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FOURTH SERIES

VOL. XL.—[WHOLE NUMBER, CXC.]

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Number 236.

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Number 237.

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Number 238.

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THE
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[FOURTH SERIES.]

Art. I.—*Factors in Movements of the Strand Line and their Results in the Pleistocene and Post-Pleistocene*;* by Joseph Barrell, New Haven, Connecticut, *including a letter on Botanical Evidences by M. L. Fernald*, Cambridge, Massachusetts.

Table of Contents.

Introduction.

The problems of the nature of the Pleistocene and post-Pleistocene movements of the strand lines and their causes are important from a number of standpoints. They constitute one of those common fields in which stratigraphy and physical geology meet. The evidence shows a complex series of movements, indicating a complexity of causes. Each locality may give indications of the existence in the recent geologic past of both higher and lower stands of the sea, recorded by such unlike features as elevated seaplains and cliffs, on the one hand, by drowned river valleys on the other. Minor rhythms of movement are superposed upon larger rhythms. What is the proper sequence, what the relative duration, and what the correlation of successive stages of emergence and submergence between different localities? As the last phase in this series of oscillations, what is the direction and amount in different regions of the last movement of the strand line?

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* Written at the suggestion of Dr. T. Wayland Vaughan and presented with lantern slides at the meeting of the Geological Society of Washington, on March 24, 1915.

Am. Jour. Sci.—Fourth Series, Vol. XL, No. 235.—July, 1915.

But after the complexities of the record have been correctly deciphered there come the questions of interpretation. The making and unmaking of the great ice sheets must, by deduction, have been the cause of very appreciable fluctuations in the volume of ocean water. To what extent does the record of movement coincide with this cause, or to what extent does the evidence show inductively that there are other equally important or more important causes? The weight of the ice sheets depressed the crust beneath them, but what was its effect on the zone of crust immediately beyond? Among other questions, if it is found that the Pleistocene and post-Pleistocene movements are to a considerable degree unrelated to glaciation, to what degree are they due on the one hand to isostatic movements, including possibly intermittent changes in the volume of ocean basins, movements merely toward crustal equilibrium; to what degree are they due to deep-seated radial shrinkage of the earth, generating rhythms of tangential compression in the crust? These factors, together with the effects of changes in crustal density, the effects of erosion, of sedimentation, and possible changes in the volume of ocean water have operated through all past time, but their effects can be most minutely studied and correctly evaluated for the recent geologic past.

When, in the future, comprehensive answers can be given to these questions, much will have been learned in regard to the nature of crustal movements, and, as the present is the key to the past, better detailed interpretations will be possible for the stratigraphic record of previous geologic periods.

Within recent years new points of view have been developed by a number of geologists in regard to present and recent movements of the sea level. Among them, D. W. Johnson has shown the necessity for a re-examination of the supposed evidences of present continuing submergence of the Atlantic shore. Daly has suggested that the rise of sea level with deglaciation may account for the appearance of subsidence of coral islands, without requiring any real movement of the crust. Vaughan has come to the view that the development of recent off-shore reef corals is closely related to a recent rise of sea level and that, in general, reef corals flourish broadly only during and immediately following submergent phases of movement. W. M. Davis has developed especially, through a critical re-examination, the evidence given by the topography of the Pacific Islands.

The writer has not entered upon this subject as a special problem for research, but in the pursuit of other investigations has several times come into contact with it. But coming unexpectedly upon a subject from an angle is apt to give new suggestions and somewhat novel points of view. It is from this standpoint that the following consideration of the subject may be of value. These points of view must be followed further and tested, however, before their results can be correctly and finally evaluated. In that brief treatment which is necessary in order to compress a large subject into the space of a short article detailed demonstrations must be avoided. The article is planned to be suggestive rather than conclusive. The purpose is to outline the controlling factors, putting the emphasis upon those aspects which have presented themselves to the writer as somewhat novel. It is not the plan here to demonstrate fully any single thesis, nor to treat in proper proportion all of the composite factors.

The Interpretation of Composite Rhythms.

The movements of the strand show a rhythmic nature. Smaller are superposed as undulations upon the larger oscillations, as, on a smaller and far briefer scale, are superposed the rhythms of waves due to wind upon those produced by tidal forces. In the interpretation of these rhythms, as Gilbert has so clearly shown, attention has been focused upon the marks of previous inroads of the sea, not upon the limits of its retreats, for these are now concealed.* To extend the analogy used by Gilbert,—if at any time we stand upon the shore and look at the lines upon the sand which mark the arrest and turning of previous waves, we see that the highest is the oldest and the successive marks form a descending series in time and intensity. We might generalize from this that the motion of the water was subsiding and the sea would therefore soon be at rest; but no sooner might this conclusion be announced than greater waves roll in, each obliterating the marks of the lesser waves preceding it, effacing also a part of the previous descending series and beginning the record of a new descending series. If we visited the shore at those rare times when a combination of spring tide and heavy on-shore storm raised the water level highest, we would at the moment of culmination see no series but only the single line of the highest wave. A visit at another time would show highest and faintest, as lines of shells and wrack, the marks made long previous during combined highest tide and storm. Below this would be the record, weeks or months younger, developed during the more moderate spring tides. Below this and still younger would be seen the marks of the waves made during the last high tide. Below this would be the series made by the combination of larger and smaller sets of wind-caused waves, the sequence recorded by

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* G. K. Gilbert, Continental Problems, Bull. Geol. Soc. Am., vol. iv, pp. 187–189, 1893.

each descending series, destroyed and covered up while we watched by the following ascending series. The tide and storm might meanwhile be rising higher, and yet the writing of the past would appear as of a subsiding nature. The lesson to be drawn is that the record of a descending series measures only the descending sequence from the last maxima of the greater rhythms. It does not in itself tell the present trend of the oscillations.

Since the end of the Oligocene the strand has, on the whole, been retreating, the continents rising higher, the climates growing colder. There seems, in the Pleistocene, to have been a culmination of crustal and climatic oscillations, closed by a descending series. Men have taken hope that the ice age is past and have looked upon the Quaternary revolution as closing. But the study of the rhythm of the waves robs us of that assurance. At several times in the Pleistocene that view, as based upon apparent subsidences of crustal and climatic movements, would have been far better justified by the evidence than it is at the present moment. The high latitudes, unlike their state through the most of geologic time, are still mantled with glaciers. The shore lines are now in a stage of earliest youth. We live in fact within the Age of Ice, within an age of crustal unrest and revolution; the geologic morrow may bring forth greater and more compelling changes than the geologic yesterday. With this understanding of the nature of composite rhythms, always seen in retrospect as ending with a descending series, we should study the record of the ocean waves made on "Time's great continental strand."

Indications of Oscillations given by Subaqueous Profiles.

The first line of investigation which led the writer to an intersection with the problem of recent strand-line movements was in a study of present shore action as a basis for the development of "Some Distinctions Between Marine and Terrestrial Conglomerates."* The pressure of other work and the desirability of making quantitative measurements has prevented the publication of more than an abstract of this article, which led up to the conclusion that "the truly terrestrial forces produce vastly more gravel, spread it far more widely, and provide more opportunities for deposition than do the forces of the littoral zone." This conclusion was reached by a re-examination of the data used by Geikie, de Lapparent, and Penck for determining the relative rates of erosion. The result was to diminish still further the ratio of marine to terrestrial erosion as given by those authors. It was estimated, by multiplying the length of shore line by the thickness

*Abstract, Bull. Geol. Soc. Am., vol. xx, p. 620, 1908.

eroded, that marine denudation for the whole earth at present amounts to probably between ·02 and ·10 cubic miles per year, whereas the rivers bring to the sea annually probably between 1·50 and 3·00 cubic miles of rock material. These wide limits must be used, since for the earth as a whole the data are as yet not on a quantitative basis. But to have any application to the geologic past the variation in rates of erosion of both marine and subaerial agencies, and the high or low values of the present rates, must be considered. Now an examination of present shores shows that they are characteristically young and the sea work is mostly erosion at certain parts of the shore, not upon the bottom. Beyond some miles off shore, deposition is in general taking place. In the oscillations of sea level the last movement therefore has, on the whole, been one of submergence and this phase is favorable for a large proportion of gravel in the marine deposits now in evidence near the shores.

Turning to the application to the present subject, it appears, by reversing the argument, that recent movements of the strand line may be elucidated by a method of study which analyzes the place and character of marine degradation and aggradation; a study pursued in a somewhat similar fashion to that study of fluviatile degradation and aggradation which has thrown such great light on the succession of crustal movements. Both rivers and sea work with respect to a base level. Their first effort is to bring a profile to a graded slope, eroding in some places, depositing in others. For the one as for the other, the nature of the work shows the direction, amount, and relative duration of recent changes of level. Valuable studies on the principles controlling the character of the shore *line* have been made by Davis and Gulliver, but what is here emphasized is the study of the water *bottom*, both near shore and offshore, its sedimentary character and its form. The basis for study consists especially of the hydrographic charts issued for the use of mariners. The writer has used particularly those published by Great Britain and the United States. The form of the bottom may be advantageously studied, not only from the plan, but by means of the projected profile. For this a section plane is taken at right angles to the submarine contours, and, to smooth out the minor effects of currents and waves and to make up for the scantiness and possible errors of the data, all soundings within a certain width are projected upon it and located as dots. A smoothed curve is then drawn through the soundings. These profiles are illustrated in figures 1 and 2.

In such studies distinction must be drawn between the subaqueous profiles of aggradation and degradation. Although in the course of unlimited time the two would tend to approach each other, yet the recurrent movements of the crust tend to eliminate this mark of old age, by creating new base levels of planation. The profiles for various grades of sediment will also be of unlike depth. Sand derived abundantly from active shore erosion may build out a subaqueous terrace at the same time that finer sediment, partly of river origin, may not be permitted to settle on the older and deeper platform beyond.

After a profile is graded, then the advance of the sea inland or the retreat of the sea, provided the level is constant, requires erosion or deposition on all parts. This graded profile is concave upward and may be called the profile of equilibrium. The depth of the profile varies greatly according to the power of the waves. Off the flat shores of quiet seas it ranges, at a distance of about ten miles, between ten and twenty fathoms. Vaughan, from his experience in the West Indies, reaches similar conclusions and considers that about ten fathoms is there the depth to which submarine erosion is vigorous. Off abrupt coasts exposed to on-shore heavy winds the profiles make it clear that it reaches to thirty or forty fathoms at the same distance.

Fig. 1.

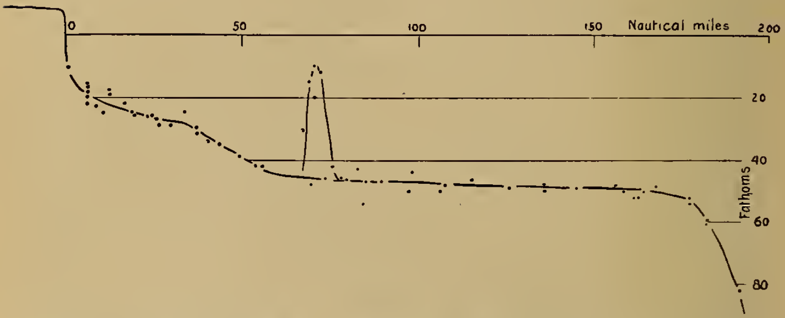

Fig. 1. Projected profile of the Argentine coast, South America. Section 50 miles wide, 25 miles on each side of a line, bearing S. 24° E. through lat. S. 38° 45′, long. 59° 20′. Vertical scale 890 times the horizontal scale.*

As observed off many continental shores these slopes at the present time may continue almost flat for twenty or thirty

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* Mr. Willis has noted in the discussion of this paper that the land surface of Argentina has been greatly affected by warping in late geologic time and that the possibility of warping should also be entertained in considering the significance of the subaqueous terraces. This is a valuable suggestion and no doubt has controlled the general form of the coast line. The development of these upper terraces at uniform levels over broad regions, however, at approximately 30 and 50 fathoms appears to indicate that their surfaces have been controlled by wave action working at these two levels at two different times later than the warping.

miles from shore. Then comes a convexity and a descent, in places to great depth, in other places, as illustrated by the shelf seas of Argentina, to broad flats about twenty fathoms deeper. Daly has been independently following the very same line of investigation, and he states in a personal communication that he has reached the conclusion that effective wave action stops much above the one hundred fathom line, notwithstanding that this has become conventionally accepted as the limit. With this conclusion the writer is in accord. Vaughan also has called attention to precisely the feature of the ocean profiles here described, noting the steep descent from about the 30-fathom to the 50-fathom curve, with gentler slopes above and below, as seen especially on the North American and Australian platforms.* E. C. Andrews, a

FIG. 2.

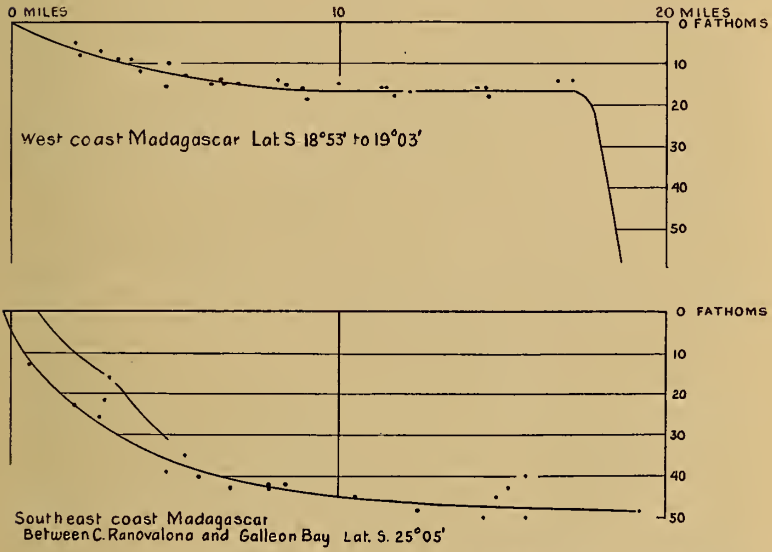

FIG. 2. Subaqueous projected profiles, coasts of Madagascar. Most of the coast shows graded, subaqueous profiles in adjustment with the present level of the sea, the wave action being relatively weak on the western side, strongest on the southeast. The figure shows how the different exposures of a coast must be considered together in order to eliminate the varying effect of the waves according to their intensity. This permits a conclusion regarding the relation of the profile to present and past water levels. Vertical scale 100 times horizontal.

*Sketch of the Geologic History of the Florida Coral Reef Tract. and Comparison with Other Coral Reef Areas, Jour. Wash. Acad. Sci., p. 33, 1914.

The Platforms of Barrier Coral Reefs. Abstract, Bull. Am. Geog. Soc., vol. xlvi, p. 427, 1914.

pioneer in thought in many fields of Australasian geology, showed in 1902 that the Great Barrier Reef of Australia stands on a platform which marks a former lower sea level. As Vaughan has stated, "The problem of the depth of barrier platforms is a world-wide one, for it is only an aspect of the general problem of the history of continental shelves."*

The study of the form of the subaqueous profiles shows, then, that they are not generally in equilibrium with wave action throughout their length. The character of the departure indicates a recent submergence. Where the shore is abrupt, as off the coast of Maine, the profile is overdeepened and the power of the waves is concentrated upon the exposed shore. Where the coast lands are very flat, as on the coastal plain, the submergence has inundated a strip which was previously land. The waves spend most of their energy on the flat bottom, miles off shore; they drag and throw up bars, partially recover their form and advance farther inshore to where barrier beaches are thrown up and cut off farther advance. The overflat bottom profile thus becomes undulatory by the shifting of material which is finally swept in part to the beach, in part to deeper water, and a normal profile becomes established. Thus it is seen that according to the form of the land submerged the profile may be overdeepened or overshallowed and the wave work becomes opposite in trend. But the cause,—submergence, may be equally clear in each.

Vaughan has developed additional criteria from the study of the shore and offshore physiography of the West Indies. He has pointed out that solution wells in the limestone show former emergence. These were made by fresh waters, and in the Bahamas are now submerged to a depth reaching 33 fathoms. There was also a still-stand of the land with the shore about ten fathoms below present level, as shown by the levels of the submerged terraces on the outside of the barrier reefs at from 8 to about 13 fathoms, with solution wells inside the barrier showing a depth from 6 to 7·5 fathoms. The filled channels of Havana harbor further substantiate the conclusion. Here there is a concurrence of evidence. From many regions, however, the other lines of evidence will be absent. There the conclusion must rest upon the testimony of the sea floor alone. When understood it is as convincing, however, as are any of the more familiar lines of evidence.

As an implication from the detailed evidence of the subaqueous profiles, it appears that the outer flats of the continental shelves still preserve to a greater or less degree the form determined by a sea level about twenty fathoms below

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* Sketch of the Geologic History of the Florida Coral Reef Tract, p. 33, 1914.

that existing at present. Still farther out there are probably terraces cut still lower. But such older steps must be commonly mantled over by the terraces of later construction, their forms would tend to become smoothed out and they are not developed by sufficient soundings to permit as yet of a detailed study. In regions where rivers do not bring much sediment from the land, however, such fossil terraces may be best preserved. For the study of the negative phases of oceanic movements,—that side of the rhythms of which, as previously pointed out, so little is known,—they should be of high importance and be best developed where the evidence given by drowned river valleys is wanting.

Pliocene and Pleistocene Marine Terraces.

The second line of investigation which has led the writer toward the problem of recent movements was in connection with areal geologic work in southern New England. An examination of the topography indicated that there were in this region a series of descending baselevels, more than could be fitted to the so-called Cretaceous, early Tertiary, and late Tertiary baselevels. The necessity of determining the number, the slope, and the age of these, as a key to the post-Jurassic history of the region led to a development of methods the results of which have been published in abstract.* Each baselevel would be recorded in the interior by surfaces of subaerial denudation, on the seaward side by surfaces of marine planation. The latter were cut as benches across the harder rocks and are consequently better preserved than the former. They were most strongly developed at the maximum elevation of the sea during each oscillation. A method of projected profiles restores these ancient levels and hides the later dissection carried on by subaerial agencies. The length of the several profiles of marine planation is related to the duration of the baselevels; their difference in elevation gives, on the other hand, the amount of elevation of the land as the result of each cycle of motion. It is thought that the Goshen level, attaining an elevation of 1380 feet in northwestern Connecticut, dates from probably the earlier Pliocene. The terraces below, facing the sea, descend by steps which are a little over 200 feet apart in elevation and many miles broad. The series resembles a flight of stairs, but one in which the rises and treads are both gently sloping and the whole so dismantled by subaerial erosion that what the eye sees in viewing the landscape is almost wholly the dissection due to later cycles of destruction. The

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* Piedmont Terraces of the Northern Appalachians and their Mode of Origin; Post-Jurassic History of the Northern Appalachians, Bull. Geol. Soc. Am., vol. xxiv, pp. 688–696, 1913.

shore lines of the terraces give the maximum elevations, the five Pliocene terraces reaching approximately to 1380, 1140, 920, 730 and 520 feet respectively. The Pleistocene terraces below were, in comparison, very imperfectly developed, but planation can be traced at stages whose mean elevations on their inner margins are 360, 220, and 100 feet. That at 220 feet is best developed, but none show the clear character of the Pleistocene terraces farther south on the coastal plain, since the Connecticut terraces were developed on formations of resistant rock. Furthermore, all are older than the last glaciation and have been obscured by that event. Their narrow breadth and originally imperfect development in comparison with the older and higher terraces appears to be a measure of an acceleration of the diastrophic rhythm in Pleistocene time. This crustal unrest is continued to the present; the present is diastrophically as well as climatically a part of the Pleistocene.

The broader Tertiary rhythm shown by the wide terraces facing the sea must be complicated in the Pleistocene by the special effects of the weight of the ice sheets, the changes in volume of ocean water related to glaciation, and the perception of the briefer minor diastrophic movements whose records are lost to sight among the larger movements of the past. These complications do not hide the facts, however, which lead to the conclusion that an abnormal crustal unrest beginning in the Pliocene has marked especially the entire Pleistocene period. The record which has been described shows the rhythmic oscillation during the upwarping and emergence of the Atlantic shore of the United States between latitudes 38 and 43 degrees. The record is different on the Pacific shores. There it is doubtless more largely related to the orogenic forces existent in latest times in the Pacific mountain system. On the eastern shore the deposits older than the Pliocene show a seaward tilt, greater for each older formation. This is a mark of progressive crustal warping. For the Pliocene and Pleistocene levels this warping, however, diminishes progressively. These later changes are more largely broad and parallel movements of level. They represent apparently more largely movements of the sea itself. To what extent, however, the net result is due to local movements of the crust cannot be determined until the series of strand lines has been studied on many shores and their resemblances and differences compared.

These high-level terraces represent the height of successive submergences. Let attention be turned next to the other side of the rhythm, that of the record of emergences, as shown by river valleys which now are drowned. Reaching far back into the Pliocene each shore line is found to be marked by large embayments developed upon regions of softer rocks. The shore lines represent therefore the rhythmic rise of the sea upon a land surface previously dissected by subaerial erosion. The baseleveling on the softer rocks near the larger streams each time during the emergent phase had reached to an advanced stage, but upon the broad formations of harder rocks it had not progressed beyond the stage of youth. The submergent phase, however, lasted long enough for the sea to produce notable planation against the outstanding harder masses. Subaerial baseleveling at these stages seems also to have made notable progress, marking times of diastrophic rest. The submergence was in each cycle great enough to permit concentration of marine erosion against the headlands, the waves not spending their force upon the bottom. The motion of the sea-level was therefore cyclic, but not smoothly undulatory. If time be laid off as a horizontal axis, the curve of sea-level was nearer to the form of the common cyloid than to the sinusoid. The variety of the cyloidal curve suggested approaches that described by a point on the circumference of a rolling wheel. This curve is characterized by a nearly flat top and a cuspate bottom. Conceive the point to be somewhat within the wheel and the pointed bottom of the curve would be somewhat broadened out. Conceive the wheel furthermore to be rolling down an irregular grade. Such a more complicated curve as would now be generated by the motion of the point may be nearer to the actual record of the sea-level movements against the Atlantic shore. It does not quite represent the discontinuous nature of the movements, but it does make graphic the conclusion that the emergent phases of the oscillations are relatively rapid and brief, the submergent phase prolonged, and marked by a slowly rising level of the sea. The retreats of the sea are thought to have been more rapid than the advances.

In Maryland broad and gently sloping terraces of Pleistocene age face the sea, bounded on the land side by low escarpments. They mark submergent phases of rhythmic crustal movements and show planation at levels of 220, 100 and 40 feet respectively, in descending order of age. The gentle seaward slopes are more or less in adjustment with the slope of the subaqueous profile of wave-worked bottoms. Within the valleys the deposits are regarded as fluviatile. Facing the sea they are doubtless marine, though the porous nature of the thin mantle of deposits has not permitted the preservation of marine fossils. The terrestrial fossils fix the age as Pleistocene. The oldest and highest deposits are known as the Sunderland formation, and are apparently of early Pleistocene age. The youngest, known as the Talbot, are judged to be late Pleistocene. The materials of all three, Sunderland, Wicomico, and Talbot, carry a large proportion of ice-borne bowlders, too large to be transported by the moderate development of river-ice now carried by the streams. They indicate thicker ice and a much colder period than at present.* These stages correspond in general to what in New Jersey, Salisbury has named the Bridgeton, Pensauken, and Cape May formations.

The oldest glacial deposits of New Jersey, represented by the patches of extra morainic drift, over the Triassic area are preserved on flat hill tops which range from 200 to 220 feet or more, in elevation. Some attenuation of the drift, ascribed to creepage, is observed below these levels, but it is inferred that the drift was laid down when the Triassic Plain was a gently undulating surface, corresponding with that whose dissected remnants are now 225 to 275 feet above the sea. The larger streams now flow at levels more than 100 feet below.† The combination of evidence from Maryland and New Jersey suggests strongly, though it lacks perhaps actual demonstration, that certain early Pleistocene stages of cold climate and glaciation occurred when the ocean level stood at the higher parts of the phases of cyclic oscillation. The statement fails of complete demonstration because the glacial deposits of New Jersey may be somewhat different in age from the Sunderland deposits of Maryland. The development of the plains at this level by subaerial erosion during crustal rest had been accomplished, at least in large part, when the ice sheets ended considerably north of their present limits, since the writer has identified baselevels of erosion at these levels in Connecticut. But the glaciation took place either before these baseleveled surfaces of soft Triassic rock had been uplifted at all or had been uplifted long enough to become dissected. The important point, however, is that the development of the cold climates, culminating in glaciation, does not appear to have required a low level of the sea, or high elevation of the land of this region. Such abstraction of ocean water as took place at these times was, therefore, more or less compensated for by occurring at the long submergent stages of the diastrophic cycles. Nothing is said here as to the attitude of the land in the centers of glacial accumulation. It is true that the central regions of glaciation are now in a depressed condition, as shown by the drowned topography. This may be the result of a lack of complete isostatic recovery after the removal of the ice load. This permanent depression is a factor, however, which would not have operated in Maryland. In conclusion, therefore, the evidence of the region marginal to gla-

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*G. B. Shattuck, The Pliocene and Pleistocene Deposits of Maryland; Maryland Geological Survey, p. 85, 1906.

†R. D. Salisbury, The Glacial Geology of New Jersey, Final Report of the State Geologist, vol. v, pp. 755-760, 1902.

ciation leans toward the view that the amount of water abstracted for the formation of the ice sheets was not a major factor in the control of Pleistocene sea levels. From the estimates which have been given by Woodward, Penck, and Daly it would seem neccessarily to have been a true and important factor, but the evidence of the Pleistocene oscillations of the Atlantic shore suggests that the diastrophic rhythm continuing with accelerated movement from the Pliocene constituted a more controlling factor.

Post-glacial Emergent Cycle Marginal to the Glaciated Areas.

The third line of investigation which led to an intersection with the problem of Pleistocene and post-Pleistocene crust movements is that connected with the Strength of the Crust, a subject now in progress of publication in the Journal of Geology. If the hypothesis set forth there is valid,—that a thick and strong lithosphere rests upon a thick zone of comparative weakness, an asthenosphere; then the weight of a continental ice sheet should tend to depress the crust into this weak zone. The crust up to a certain limit would yield as an elastic plate, the asthenosphere would reach its elastic limit at a far earlier stage and from that point yield by flowage, a flowage, it is thought, which is akin to the recrystallization which explains glacial flow. But as this subcrustal zone is not a fluid, it cannot transmit the excess pressures to unlimited distances. Broad and low pressure ridges would tend to be raised therefore beyond the limits of the ice sheets. A railroad embankment sinking into a marsh and elevating slightly the adjacent portions of the marsh offers an instructive analogy. Upon the removal of all of the embankment, including that which had sunk below the marsh level, a re-elevation of the central tract toward the original level would occur. The lateral pressure ridges might rise at first with the central part and then subside. This double motion would be favored if the deeper levels of the marsh were the more nearly fluid and if the removal of the load was very rapid, exceeding the rate of readjustment for the upper levels.

Does the expectation raised by this hypothesis correspond with the known depression of the crust under the Pleistocene continental ice sheets and the recovery from that depression which followed the retreat and disappearance of the ice? The question serves in a measure as a test of the validity of the initial hypothesis regarding the distribution of strength in the outer earth. As giving such a test the problem was investigated, though, as it is somewhat apart from the principal subject, it is not intended to publish the results as a part of the series on the Strength of the Crust, but rather later as a separate article.

The results of that investigation in so far as they bear upon the post-glacial crustal movements may here be touched upon, but within a short article the detailed arguments cannot be given. These results cannot therefore logically be used here as proofs regarding the nature of recent movements, but may serve as suggestions: the deductive conclusions from a hypothesis must be subordinated to the direct inferences from established facts, but the deductions may serve, nevertheless, to emphasize, explain, and coordinate such inferences.

This theory of the distribution of crustal strength was applied to the data regarding water levels during the retreat of the ice, and their correlations as given by Woodworth for the Champlain and Hudson valleys.* The accuracy and clearness of presentation of this difficult subject by Woodworth when combined with this theory permitted the determination of the sea level in latitude 40° north for each stage of the ice retreat. This is at a distance where the weight of the ice should have had no direct influence and represents the movements in a belt beyond the terminal moraines. As previously noted, however, the results of such an investigation are to be regarded as suggestive rather than conclusive. When the ice had retreated about to lat. 42° 45′, some 150 miles back from the terminal moraine, the sea level near the ice front stood 430 feet above the present level. The projection of the curve of flexure points to a sea level at latitude 40° 40 feet lower than at present. When the ice had retreated to lat. 43° 30′ the sea level there stood at +560 feet; at latitude 40° the appropriate curve suggests a sea level at —90 feet. When the Champlain marine water body existed, its slope and the appropriate curvature point to a water level of —220 feet south of the terminal moraine. These figures have of course no exact value, but if they are in the direction of the truth they mean that south of the limit of glaciation the coastal plain of the Atlantic shore was higher than at present and rising, the sea sinking, during the retreat of the ice, and that in later post-glacial time a marked submergence of this region has taken place to the present level. This emergence and submergence are of an opposite character to the effect of the addition of water to the ocean by deglaciation and are distinct from the marked isostatic rise of the glaciated region toward the present level, a rise which accompanied the removal of the load of ice.

Are there independent lines of evidence pointing in this direction, evidence strong enough to make a real case and not depending upon the grist of a mathematical mill, grinding out

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* Ancient Water Levels of the Champlain and Hudson Valleys, Bull. 84, N. Y. State Education Department, 1905.

the results of certain hypotheses? Such independent evidence will now be considered.

Woodworth has called attention to evidence that at some time since the retreat of the ice the land has stood higher than at present. South of Albany many of the tributaries appear to be now filling up excavations below sea level which at some previous time they had cut into post-glacial deposits.* In the gorge of the lower Hudson River silt extends to variable depths, 280 to 320 feet at New York City. At the Storm King Crossing of the Hudson River, borings for the new aqueduct encountered the highest stratum of bowlder beds at a little over 200 feet in depth. These appear to be deposits not excavated by river action since the ice retreated. The evidence shows, therefore, that a stage of emergence has occurred since the retreat of the ice but that this emergence above present level was not over 200 feet as a maximum. It may have been less.

Evidence that a minor cycle of emergence and submergence has occurred since the retreat of the ice is also found along the shores of southern New England and the south. The submergence to present level appears not to date back more than a few thousand years at the most, as is shown by the extreme youth of the shore line. Headlands have barely begun to be cut into, embayments have only begun to be filled. Sediment carried in by the tides forms salt marshes which are still flooded at spring tides. Deltas at drowned river mouths have barely begun to form.

It happens, however, that near the margins of glaciation the latest submergence has brought the present sea level only slightly above that which existed at the beginning of the retreat of the ice. The physical evidence for a rapid cycle of post-glacial emergence of considerable amount, involving a tract beyond the limits of glaciation, is therefore drowned and the amount and importance of the emergence is perhaps best given by the distribution of plants along the Atlantic shore from New Jersey to Newfoundland. Britton, Hollick, and others have discussed the significance of plant distribution, especially of southern types of the Coastal Plain, but the most important contribution on this subject has come from Fernald in his analysis of the flora of Newfoundland.† He points out that 118 species of plants belonging to the Pine Barren and Coastal Plain floras of New Jersey and the south are known from remote outlying stations along the coastal strip of New England and the Maritime Provinces. Most striking, however, is the evidence from Newfoundland. He shows that 60

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* J. B. Woodworth, loc. cit., pp. 229–234, 1905.

† M. L. Fernald, A Botanical Expedition to Newfoundland and Southern Labrador, Rhodora, vol. xiii, pp. 109–162, 1911.

per cent of the plants are boreal types. Only a few plants are present out of the hundreds which constitute the flora typical of Canada in the same latitude. On the other hand 35 per cent of the plants of Newfoundland are southwestern types and 7·7 per cent of these are plants characteristic of the coastal plain of New Jersey and the south. Fernald shows, by means of the evidence of the flora, the ineffectiveness of winds and currents to transport across the Gulf of Saint Lawrence to Newfoundland the typical Canadian plants, though the boreal types may have entered across the comparatively narrow straits which separate the island from Labrador. Fernald argues that it would be still more difficult for winds and currents to act as agents for the migration of the Coastal Plain flora. Not only are the distances vastly greater, but the winds and currents move actually in the wrong direction to carry plants from the southwest.

Migrating birds can hardly be invoked. The nearest land to the southwest of Newfoundland is Cape Breton Island at a distance of 70 miles and many of the species of plants which are concerned are rare and local at all points northeast of New Jersey, a distance of over 850 miles. Studies of migrating birds, especially in connection with the flora of the Faröe Islands, have shown that they reach the end of their flights with intestines empty.

A remaining hypothesis is, that after the last retreat of the ice, the Coastal Plain stood higher and offered northeastward a line of passage broken only at a few places by channels of deep water. A climate warmer than the present would favor this migration of the flora of the southern Coastal Plain. An elevation of at least 100 or better 150 to 200 feet, enduring for some thousands of years, would apparently be needed to give the necessary conditions for plant migration. An elevation of 200 feet would still involve, however, the crossing of 70 miles of water in Cabot Strait. An elevation of the Coastal Plain seems the readiest way of explaining the existence of such isolated stations of southern plants as that of *Magnolia virginica* at Cape Ann, Massachusetts, but migration from the southwest is difficult to apply to Newfoundland. For this it may be necessary to invoke another aspect of the same hypothesis of elevation.

The Great Banks extend 200 miles southeast of Cape Race, to latitude 43 degrees. The Gulf Stream flows past not far distant on the south and must serve to ameliorate the climate. Nearly to the margin of the Banks the depths range no deeper than from 30 to 40 fathoms. If, during and for a time following glaciation, this region was above sea level and unglaciated, it may have served as a haven of refuge for plants of the Coastal Plain, requiring a temperate climate.

In his first publication Professor Fernald had given much weight to the suggestions derived from Penck and Daly,—that the ice of the continental glaciers abstracted so much water from the ocean that an emergence would be expected of part of the continental shelves. But against this cause as an agent operative in this instance it is to be noted that in direct proportion as the climate became warmer and the ice withdrew such an emergence would have disappeared. The character of the flora suggests, however, that the migration to the present isolated localities must have taken place during a period of climate even warmer than the present and at a time after the ice sheets had given up their water. This aspect tends to rule out the availability of the hypothesis that emergence was controlled only by the level of the ocean water as controlled in turn by glaciation. In response to questions by the writer regarding the indications of the plants as to the climatic conditions which would favor their migration and successful competition with other floras, Professor Fernald, under date of January 15, 1915, wrote a letter, which because of its great value on the problem of recent crustal movements is quoted here nearly entire.

Botanical Evidences.—A Preliminary Statement of Results of Studies on the Northeastward Distribution of the Coastal Plain Flora, by M. L. Fernald:

The question you raise, of the probable period and climatic conditions of the migration of southern coastal plain plants to Newfoundland, is one on which there is now accumulating a vast amount of evidence. Since I published a preliminary statement of the case I have had parts of two seasons in Newfoundland where I secured much more similar material, a season divided between Prince Edward Island and the Magdalen Islands, which have a flora much more southern than boreal, with many New Jersey Pinebarren species, a summer on Cape Cod and Black Island, where there are still larger proportions of such cases. One of my research students, Mr. Harold St. John, has spent a season on Sable Island, getting evidence in the same line, and another season on the Magdalen Islands, and he is now working on the results as his doctor's thesis. Another graduate student, Mr. Sidney F. Blake, has spent a season on Northumberland Strait and the sands of northeastern New Brunswick, where he secured further material upon which his thesis will be based.

Briefly, we have in southern Newfoundland (south of the North Peninsula) a large number of species of southern origin, some even of tropical affinity. Further, on the shores of Dawson's warm Acadian Bay (see Dawson, Canadian Nat., ser. 2, vii, p. 277, 1875), including the region from Cape Breton to the south side of Baie des Chaleurs, i.e., eastern Nova Scotia, eastern New

Brunswick, Prince Edward Island, and the Magdalen Islands, we find many such species, some identical with, others different from those reaching Newfoundland, and on Sable Island there are some similar cases, some of the species from the south getting to Sable Island but not to the other areas. Now it is inconceivable that these southern types should have extended to these remote outlying areas under conditions much colder than at present, and judging from their present very restricted occurrence in these northern regions it looks as if they must have reached them during a period somewhat warmer than at present. They either migrated northward on the continental shelf prior to the Wisconsin glaciation and persisted outside the subsequently glaciated area, finally taking possession of their present isolated habitats on the receding of the ice or, as seems to me perhaps equally probable, the continental shelf, including the present southwestern half of the Gulf of St. Lawrence, must have been considerably elevated after the Wisconsin, long enough for the migration—including some mammals, and even fresh water and land snails.

The question is complicated by a mass of evidence not yet published upon: briefly that in the regions above enumerated, there is also a remarkable proportion of the flora, quite unknown elsewhere in North America, which is strictly identical with the flora of the Atlantic area of Europe, even including the Azores. We have startling cases (several scores of them) of species strictly indigenous in Newfoundland and known otherwise only in the region from the North Sea to Portugal, or to western France, and in some cases also on the Azores or even Madeira. Similar and very striking cases have come to light on Sable Island, the Magdalens, Prince Edward Island and eastern New Brunswick, indicating pretty clearly a large flora (and snail fauna, too) which must have crossed on the mid-Tertiary land and been stranded at the present margins of the Atlantic. Now these cases imply some tract along the coast, especially of Acadia, and Newfoundland, which held this flora and fauna continuously through the Pleistocene. . . . .
Another point: in a few cases plants clearly indigenous on these isolated areas, Newfoundland, Sable Island, Prince Edward Island, etc., are species identical with, or representative of, the Australasian flora, and seem to be harking back to the Eocene. So you see, that it is not very easy to give an offhand brief answer to your inquiry about the botanical evidence. My students, Messrs. St. John and Blake, and I are wading aboutin a flood of such evidence, trying to work out the exact identities and affinities and come to safe anchorage, but it is a vast problem and every species has to be studied intensively, often requiring a complete monographic study of a world-wide group before we are sure of our ground.

It will be a long time before we are able to publish our detailed results. If you wish to use the above as a preliminary statement you may do so.

Evidence somewhat similar to that which has been so strikingly presented by Fernald is found on the shores of northwestern Europe, of land emergence above the present level involving regions beyond the limits of glaciation and occurring in a warm stage following the retreat of the ice. This is presented in comprehensive form by W. B. Wright of the Geological Survey of Ireland in his recent book on "The Quaternary Ice Age." Before the glacially depressed region had recovered in Scandinavia all of its present elevation, there was a rapid uplift to the south which cut off the connection of the Yoldia (enlarged Baltic) Sea with the Atlantic and produced the Ancylus lake. The climate was notably warmer than at present, as recorded by the advance of the hazel (*Corylus avellana*) and other plants to regions well beyond their present northern limits. The same climatic optimum has been proved in Finland, for at a certain floral horizon (the upper portions of the Birch–Fir zone) certain warmth-requiring plants made their appearance in localities far north of their present northerly limits.* In southern England forest beds which are correlated with this stage are found submerged now to a depth of 55 to 60 feet, indicating a post-glacial uplift of land to a height well above the present sea level.

Wright considers the breadth of this movement as indicative of a general lowering of sea level and seeks its cause in a recrudescence of some one of the ice sheets, possibly that of the Antarctic continent.† But the general warmth of climate existing at that time does not favor such a view. So far as the evidence goes two other hypotheses are preferable.

One of these hypotheses is that the post-glacial emergence and following submergence represent a diastrophic emergent cycle entirely unrelated to glaciation, one of the movements in the complex rhythms which have been traced in southern New England through Tertiary and Quaternary times. If so, it should be in part a sea-level movement, and traceable widely over the earth.

The other hypothesis involves less widespread effects. It is that which was discussed in the pages leading up to the botanical evidence. This hypothesis is, that the weight of the ice sheets caused crustal depression directly below the load, but moderate elevation in a wide zone beyond the load. Upon the removal of the ice it appears the first isostatic upwarping carried up higher this marginal upwarped zone with it. Being already an upswollen tract the broader regional movement carried it up to a level where it became unstable and a slow settling back occurred as an after effect, coincident with the

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* W. B. Wright, loc. cit., p. 437, 1914.

† Loc. cit., p. 417, 1914.

last stages of upwarping over the centers of glacial load. The actual evidence at hand does not decide between these hypotheses. The association with the close of glaciation appears to favor a genetic connection with deglaciation, but on the other hand it remains to be demonstrated why the extra-marginal zone should rise together with the region directly glaciated, or that the cycle was restricted to such an extra-marginal zone.

Possible effects of radial shrinkage.

The fourth line of intersection with the problem of recent movements was the result of a query raised by Professor Schuchert in 1909 as to the quantitative effect of earth shrinkage in producing an increased speed of diurnal rotation, and a greater oblateness of the earth's figure; tending to raise the level of ocean waters toward the equator, and to depress the ocean level near the poles. Calculations made by the writer for Schuchert in regard to the possible magnitude of this effect suggested that it might be of very real influence.* A radial shrinkage of a mile, it was estimated, would increase the difference between equatorial and polar radius by about 90 to 100 feet. If this difference were taken up wholly by adjustment of ocean level and not by internal earth adjustment, a supposition which can be true to only a limited degree, then a shrinkage of a mile in radius would raise the water level at the equator about 35 feet, while at the poles it would sink about 60 feet. In latitude 35 degrees the water level would suffer no change.

The rigidity of the earth in an east-west direction is also found to be different from that in a north-south direction and may have some influence on mode of crustal yielding.

But to be of influence in a result, a factor must not only be real; it must, furthermore, be of quantitative importance. Such great folding and thrusting movements as have occurred in the later Tertiary suggest that earth shrinkage is an important factor. Schuchert has called attention to the greater persistence of equatorial epeiric seas and the readvance of waters more frequently from lower toward higher latitudes.

The southward bends of certain rivers such as the Delaware and Susquehanna along the strike of soft formations has received various explanations. In so far as land emergence is produced by sea-bottom subsidence or is coincident with movements of crustal shortening, the retreating sea should also slightly change its slope. It is possible that such a slight change in slope of sea level at the time the lower river courses were established on a newly emerged coastal plain may be at

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*Charles Schuchert, Paleogeography of North America, Bull. Geol. Soc. Am., vol. xx, pp. 505-508, 1910.

least a partial cause of the southward deflections of rivers which were established along the Atlantic margin in late Tertiary time. Such a possibility should at least be added to the group of multiple hypotheses which have been brought to bear upon the problem. In the emergence of a sea bottom, the more important control of the slopes is due to the slope of the previous surface of sedimentation and the later local warpings of the crust, but a component tending to make for deflections toward the equator may be due to more broadly acting forces, and at certain times and places it may rise to the rôle of an important factor.

Conclusions.

To review in conclusion the factors which appear to enter to a greater or less degree into Pleistocene and recent crust movements,—First, we must recognize the *climatic factors* connected with Pleistocene glaciation. These consist in the abstraction of the vast quantities of ocean water which accompanied the development of the ice sheets; the direct depression under the load of ice; a possible compensatory elevation in a somewhat broad zone beyond; a deferred, intermittent, and possibly oscillatory readjustment upon the removal of the burden of ice.

But these factors related to glaciation must not be used alone. There are other factors unrelated to climatic causes which may be of equal importance. The second group of causes includes the movements which tend to maintain the equilibrium of large sections of the crust, affect the whole ocean level and locally warp the lands, but do not involve earth shrinkage. It is thought that they find their cause in a lack of equilibrium of pressures upon that zone of the earth's body which lies just below the level of isostatic compensation. They are then the isostatic factors. The general rise of lands which has marked the later geologic times may most probably be placed in this category, due either to changes of external load, or to changes in crustal density. This would include a possible enlargement or deepening of portions of the ocean basins. As continental rejuvenation is the chief effect, these adjustments toward the maintenance of isostasy may be called *epeirogenic factors.*

The third group of causes are thought to be found in great compressive movements in the lithosphere, which seem to be due in turn to a shrinkage of the centrosphere. Locally they may work against isostasy, more broadly they may start isostatic movements. As their ultimate expression is in mountain building along lines of weakness they may be classed as *orogenic factors.*

Fourth are the *planation factors*, working in opposition to isostasy. They are the forces which tend to erode the lands, fill the seas with sediment, and raise their surface level. Added to this is whatever slow and secular gain the ocean makes in the volume of its water.

The combinations of isostatic and compressive forces have together operated through geologic time. The causes are complex and the result is seen in the composite diastrophic rhythms which are expressed in all ages but which can be studied best and more definitely in the record of the latest times.

To sift apart the factors, comprehensive investigations must be prosecuted over different parts of the earth. The sequence and amount of oscillations in the tropics must be linked to those of higher latitudes. Changes of sea level must be separated from local changes in the level of the crust. Multiple working hypotheses must be tested by the application of new and significant facts.

When, as Gilbert says in the introduction to his monograph on Lake Bonneville, "the work of the geologist is finished and his final comprehensive report written, the longest and most important chapter will be upon the latest and shortest of the geologic periods".

Art. II.—*The Heat of Formation and Polymerization of some Oxides and Determination of the Heat of Combination of Water by Fusion with Sodium Peroxide;* by W. G. Mixter.

[Contribution from the Sheffield Chemical Laboratory of Yale University.]

The heat of formation of an oxide may be determined directly by combustion, or it may be derived from the heat of the reaction of a metal and its oxide with water, or acids, or sodium peroxide. The thermal result is usually for an oxide formed at a high temperature and above that at which a given hydroxide glows. In the article* on chromium and aluminum sesquioxides it was shown that the heat of polymerization of the former is not small. The present paper contains results obtained with other oxides and also determinations of the heat effect of combined water in fusions with sodium peroxide.

The heat of combination of some oxides with water is found by direct treatment with water, or the same result may be obtained by dissolving the oxide and the corresponding hydroxide in an acid. When an hydroxide or oxide becomes anhydrous at low temperatures the method of fusion with sodium peroxide applies as shown later. The heat effect of the combined water is the difference between the heat of fusions of mixtures of sodium peroxide and the hydrous and anhydrous compound, if the latter is not a polymer. This value subtracted from the heat of the reaction of water and sodium oxide is the heat of combination of the water with the anhydrous compound. As is well known, some oxides retain water at temperatures below that at which they glow and polymerize. The heat of combination of such water can only be estimated approximately.

The heat of the reaction between water and sodium peroxide is derived from the heats of formation of the peroxide, water and sodium hydroxide, thus

$$\underset{119{\cdot}8}{(2\mathrm{Na} + 2\mathrm{O})} + \underset{68{\cdot}4\ (\text{Thomsen})}{(2\mathrm{H} + \mathrm{O})} = \underset{203{\cdot}7\ (\text{Thomsen})}{2(\mathrm{Na} + \mathrm{O} + \mathrm{H})} + \mathrm{O} = 15{\cdot}5\ \text{Cal.}$$

and 19·4 Cal.† are required to separate the oxygen. Hence

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* This Journal, xxxix, 295, 1915.

† De Forcrand found in 1898 (C. R., cxvii, 514), $2Na + 2O = 119{\cdot}8$ and $Na_2O + O = 19{\cdot}4$. Recently (C. R., clviii, 991, 1914) he obtained 119·7 and 19·03 Cal. respectively. I have used the value 19·4 Cal. in previous work and the results have accorded well with those obtained by combustion in oxygen or other methods. This value is used in calculating the heat effect of oxygen liberated in fusions with sodium peroxide. For each cubic centimeter of oxygen at 0° and 700^{mm} pressure 1·734 small calories are added to the observed heat of an experiment.

15·5 + 19·4 = 34·9 for the heat of combination of sodium oxide with water. Beketoff, however, found that Na_2O + aq = 55·5 and Rengade, 56·5. The mean 56 − 19·9 (the heat of solution of 2NaOH), = 36·1 for the heat effect of $Na_2O + H_2O$. It is impossible to say which is the better one of the two values, but 36·1 accords best with the results obtained with gypsum and brucite and is the one used in this paper. When a combustible substance, such as sulphur or carbon, is mixed with the peroxide and an hydroxide, and the mixture ignited, sodium oxide is formed thus:

$$S + 3Na_2O_2 = Na_2SO_4 + 2Na_2O$$

and the sodium oxide unites with the combined water to form hydroxide. If the mixture contains brucite the reaction then is

$$S + 3Na_2O_2 + MgO.H_2O = Na_2SO_4 + MgO + 2NaOH + Na_2O$$

and the heat effect in excess of that due to the sulphur is

$$(Na_2O + H_2O) - (MgO + H_2O)$$

The method of fusion with sodium peroxide on hydrates was first tried with hydrous calcium sulphate because Thomsen found the heat of combination of water with anhydrous calcium sulphate. For the work $CaSO_4.2H_2O$ was precipitated from a cold solution of calcium chloride by sulphuric acid. After standing a day it was washed and dried over oil of vitriol in a vacuum. It lost on heating 20·9 per cent; calculated for $2H_2O$, 20·9 per cent. The anhydrous sulphate used in experiments 1 and 2 was obtained by heating the hydrous salt at 160° until the weight was constant, while that used in experiment 3 was heated to 200°. In experiments 4 and 6 the $CaSO_4.2H_2O$ made was used, and in 5 a good specimen of selenite. It was impossible to mix thoroughly by shaking together in the bomb, sulphur, the precipitated $CaSO_4.2H_2O$ and sodium peroxide. The fine sulphur apparently was electrified, for some of it adhered to the bomb and did not burn completely when the fusion occurred. In some experiments a little free sulphur remained, and in all cases where the mixtures were made in the bomb the results were low and considerable silver sulphide was formed. The mixture for experiments 3 and 5 were made in a mortar. In 3 and 6 lampblack was used in place of sulphur and the mixing was made by shaking the ingredients in the bomb closed by a glass plate. The experimental data are given in Table I.

The mean of 1, 2 and 3 for $CaSO_4$ is 323 cal., which gives 43·7 Cal. for 1 gram molecule. It was found that calcium

TABLE I

	1	2	3	4	5	6
$CaSO_4$ (a)	4·026	4·865	5·166			
$CaSO_4.2H_2O$ (b)				3·085	3·000	5·233 g
S	1·000	1·000		1·000	1·000	
Lampblack (C)			1·290			1·274
Na_2O_2	13·5	14·	24·	19·	18·	22·
Water equiv. of system	4122	4056	4112	4138	4125	4166
Temperature interval	1·612	1·709	3·745	1·777	1·764	4·076°
Oxygen set free	0	0	0	0	0	0
Heat effect	6645	6932	5400	7353	7277	16981 cal
" " of S	−5300	−5300		−5300	−5300	
" " " C			−13722			13551
" " " Fe	−40	−42	−40	−40	−40	−40
" " " a (c)	1305	1592	1638			
" " " b (d)				2013	1937	3390
" " " 1 g. of a $\frac{c}{a}$	324	327	317			
" " " " " b $\frac{d}{b}$				653	646	648

oxide gives no heat effect in fusion with sodium peroxide and sulphur, hence the heat effect of $CaSO_4$ is from the reaction of this compound with sodium oxide as shown in equation 1 below. The mean of 4, 5 and 6 for $CaSO_4.2H_2O$ is 649 cal., or 111·6 Cal. for 1 gram molecule.

The calculated heat effect of 1 gram of sulphur reacting with sodium peroxide is 5300 cal. and this value is used because Thomsen's values are adopted in the equations 1, 2, 3 and 4, given later. The lampblack used was of the lot used in previous work.†

$$(1)\quad \underset{332·4}{(Ca + S + 4O)} + \underset{100·3}{(2Na + O)} = \underset{328·6}{(2Na + S + 4O)} + \underset{145.}{(Ca + O)} + 40·9 \text{ Cal.}$$

The experimental result is 43·7 Cal. Including sulphur and sodium peroxide in the calculation, we have

$$S + \underset{359·4}{3\,(2Na + 2O)} + \underset{332·4}{(Ca + S + 4O)} = \underset{657·2}{2(2Na + S + 4O)} + \underset{145}{(Ca + O)} + \underset{100·3}{(2Na + O)} + 210·7 \text{ Cal.}$$

The calculated heat of the reaction between sulphur and sodium peroxide is 169·8 Cal., and adding this to 43·7 gives 213·5 Cal. for the observed heat effect. For the hydrous sulphate we have

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† Loc. cit.

$$\mathrm{S} + \underset{359\cdot4}{3(2\mathrm{Na} + 2\mathrm{O})} + \underset{473\cdot9}{(\mathrm{Ca} + \mathrm{S} + 6\mathrm{O}+4\mathrm{H})} + \underset{100\cdot3}{(2\mathrm{Na} + \mathrm{O})} =$$

$$\underset{657\cdot2}{2(2\mathrm{Na} + \mathrm{S} + 4\mathrm{O})} + \underset{145}{(\mathrm{Ca} + \mathrm{O})} + \underset{407\cdot5}{4(\mathrm{Na} + \mathrm{O} + \mathrm{H})} + 276\cdot1 \text{ Cal.}$$

The experimental result is 169·8 + 111·6 = 281·4 Cal.

The results with $CaSO_4$ and $CaSO_4.2H_2O$ are somewhat higher than the values derived from Thomsen's data. Whether the difference is due to errors or to CaO set free from the sulphate combining with sodium oxide, or to other causes, cannot be determined. It has been stated that CaO made by heating the carbonate gives no heat effect in the fusion. CaO separated from the sulphate may be in a different molecular state from the intensely heated oxide.

The difference found between the heat effect of $CaSO.2H_2O$ and $CaSO_4$ is 111·6 − 43·7 = 67·9. The number taken for the heat of the reaction of $H_2O + Na_2O$ is 36·1 (p. 24). For free $2H_2O$ it is 72·2. Hence for the heat of combination of $2H_2O$ with $CaSO_4$ we have 72·2 − 67·4 = 4·8 Cal. Thomsen's value is 4·7.

The work with gypsum has been given in detail as it illustrates well the method of fusion with sodium peroxide for determining the heat of combination of water.

Brucite, $MgO.H_2O$.—The mineral used was a good crystalline specimen. An analysis gave the theoretical quantity of water, 0·3 per cent FeO, and traces of Mn and Ca. Two calorimetric tests were made of the MgO from heating the brucite with the result of 0, and 13 cal. per gram. One of pure MgO gave 13 cal. Three determinations of the heat effect of brucite in mixtures of sulphur and sodium peroxide gave 476, 438 and 456 cal. With lampblack in place of sulphur the result was 461 cal. The mean 458 × 58·3 = 26·7 Cal. This number subtracted from 36·1 gives 9·4 Cal. for the heat effect of $MgO + H_2O$. From Richards' result for the heat of solution of magnesium in hydrochloric acid, Thomsen's values for the heat of solution of the chloride, etc., and Van Wartenberg's Mg + O = 143·6 is derived 7·0 Cal. This value is for precipitated $Mg(OH)_2$, which is commonly regarded as amorphous.

Ferric Hydroxide.—Ferric hydroxide after drying in vacuo was found to have the composition $Fe_2O_3 + 1\cdot96H_2O$. When mixed with sodium peroxide the mixture became warm, hence the preparation was not available for the calorimetric work. Next ferric hydroxide was precipitated from a boiling solution of the chloride by ammonia and the whole was kept hot on a steam bath for several hours. The precipitate was washed with hot water and dried in the open air. After pulverizing it was left nine days over solid potassium hydroxide. This preparation, designated as A^1, lost on ignition 11·3 per cent and after remaining a year and a half in a rubber-stoppered bottle the loss was 11·6 per cent. It is marked A^2. The substance was free from chlorine. Preparation B was made from Kahlbaum's ferric hydroxide, having the composition approximating to $Fe(OH)_3$, by heating for three days at 200–230. It contained a little chlorine and lost on ignition 1·9 per cent. Next an attempt was made to dehydrate ferric hydroxide at 100° by the well-known method of boiling. For this purpose an excess of ammonia was added to a boiling solution of ferric chloride in a flask connected with a reflux condenser and the boiling over a Bunsen burner was continued eight days. The solution, of course, became slightly acid. A portion of the precipitate was washed by decantation until it became a slime and ceased to settle. Then some ammonium nitrate was added to coagulate it and the washing was continued. Finally the precipitate was collected on a filter and dried at 100°. It was free from ammonia, but contained a trace of chlorine. It lost on ignition 2·7 per cent. The preparation is designated as C.

The dehydration just described may be due to contact with the glass, which was above the temperature of the boiling solution. One experiment made supports this view. Ferric hydroxide was precipitated as before and the flask containing it was surrounded by steam for eight days. The solution became acid as before. The precipitate was washed, dried at 100°, and then digested with ammonia to break up oxychloride present and washed again. Finally it was dried, pulverized and heated in a weighing bulb for 24 hours at 100°, losing 0·1 per cent the last 12 hours. This preparation lost on ignition 9·27 and 9·32 per cent.

Preparation D was made from Kahlbaum's ferric hydroxide, which was in the form of fine grains. It was washed with hot water, digested with ammonia and washed again with hot water. Next the substance was dried at 100°, sifted, and only the fine powder used. A portion of the powder, after heating at 100° to expel hygroscopic moisture, lost on ignition 6·2 per cent. The remainder of the powder, 58 g., was heated four days at about 160°, losing the last day 0·08 g. This preparation lost on ignition 2·65 and 2·61 per cent. It contained no chlorine.

In a former paper* it was shown that 1 g. of ferric oxide which has been subjected to a dull red heat reacts with sodium oxide to form sodium ferrite with a heat effect of 363 cal. Hence, after finishing the work on the various samples containing water, it seemed desirable to learn whether ferric oxide which had been exposed to a higher temperature than a dull red would give a different result than the one given above.

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* This Journal, xxxvi, 55.

For this purpose the preparation designated as E was made as follows: a portion of D (which was a soft red powder containing 2·6 per cent of water) was heated very gradually to approximately 1000°* and then kept at this temperature two hours. The oxide resulting was in the form of a dark gray friable mass. It was easily rubbed to a powder and was passed through a mesh less than 1/200 of an inch. The powdered oxide, after heating twice as described, showed no change in appearance and each time formed a coherent mass. It was found not to change weight during the last heating and to be free from ferrous oxide. The dark gray powder turned dark red when finely ground. It was not too coarse for the calorimetric experiments. The mean of the results for E is 361 cal. This does not indicate polymerization of ferric oxide between a dull red heat and 1000°.

The results obtained with ferric oxide holding various amounts of water are given in considerable detail in Table II, as they show that the experimental errors are probably small. The values obtained for D and A^2 are the best because of the purity of the preparations used, and only these values will be discussed. The mean for D is 425 and for A^2 is 529. The 2·6 per cent of water is undoubtedly more firmly held by the ferric oxide than the 11·6 per cent. If it is assumed that the heat of combination of 1 g. of water in both A and D is the same, the error will not be great, for the proportion of water in D is small. Furthermore, it is assumed that the ferric oxide is in the same molecular state in both D and A^2. Then if x equals the heat effect of 1 g. of ferric oxide in the fusions and y that of 1 g. of water combined with the ferric oxide, we have

$$0·974x + 0·026y = 425$$
$$0·884x + 0·116y = 529$$

$x = 398$ Cal. for 1 g. of ferric oxide. The heat of fusion of 18 g. of water is 1·44 Cal. and $36·1 - 1·440 \div 18 = 1·9$ Cal. for the heat effect of 1 gr. of solid water reacting in the sodium peroxide fusions. Assuming that in D the solid water is not combined with heat effect, we have

$$425 - (0·026 \times 1·19 \text{ Cal.} \div)\ 0·974 = 385 \text{ cal.}$$

for 1 g. of ferric oxide. Hence, on any assumption the ferric oxide in D which had been heated only to 160° polymerizes at high temperatures. The difference between 398 and 363 is 35 cal. and for a gram molecule of ferric oxide, 160 g., it is 5·6 cal.

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* Silver, m. p. 960°, melted in the electric furnaces used, but gold, m. p. 1060°, did not melt.

TABLE II

	A¹ Fe_2O_3 88·7, H_2O 11·3		B Fe_2O_3 98·1, H_2O 1·9		C Fe_2O_3 97·3, H_2O 2·7		D Fe_2O_3 97·4, H_2O 2·6		A² Fe_2O_3 88·4 H_2O 11·6		E Fe_2O_3 at about 1000°	
	1	2										
Substance	5·000	5·000	5·043	4·986	5·323	4·972	5·845	6·141 g.	5·40	6·236 g.	5·200	5·413
Sulphur	1·500	1·500										
Lampblack (C)			1·076	1·057	1·075	1·242	1·005	1·182	1·061	1·077	1·109	1·283
Sodium peroxide	21·	20·	18·	19·	18·	23·	23·	22·	25·	25·	22·	26·
Water equiv. of system	4127	4141	4100	4132	4159	4196	4136	4208	4150	4187	4169	4192
Temperature interval	2·506	2·500	3·296	3·216	3·215	3·612	3·078	3·532	3·330	3·348	3·225	3·640°
Heat effect observed	10342	10352	13514	13288	13371	15155	12716	14860	13819	14170	13445	15259 cal.
" " of S or C	−7860	−7860	−11444	−11242	−11435	−13210	−10690	−12573	−11280	−11452	−11567*	−13392*
" " " F iron	−40	−40	−40	−40	−30	−30	−30	−30	−30	−30	−24	−24
" " " O_2 set free	+48	+64	not observed	+116	+250	+147	+472	+377	+348	+612	0	100
" " " substance	2490	2516	2030	2162	2156	2062	2468	2634	2857	3300	1845	1998
" " " 1 g. of substance	498	503	403·	434	405	415	422	429	529	529	355	367

* 1 g. new lot of lampblack gave 11437 cal.

The values for the heats of formation of the oxides and hydroxides of iron are 2Fe + 3O + Aq = 191·3 (Thomsen), Fe + O + Aq = 68·3 (T), $2Fe(OH)_2$ + O + Aq = 54·6 (T), Fe + O = FeO (900°) 64·3,* 2Fe + 3O = Fe_2O_3 (ignited) 192·2* and 2FeO (900°) + O = Fe_2O_3 (ignited) + 63·7.*

The heat of formation of ferric oxide derived from that of ferrous oxide and Thomsen's value for the oxidation of ferrous hydroxide is 2 × 64·3 + 54·6 = 183·2 or 9 Cal. less than that of ignited ferric oxide. And the heat of oxidation of ferrous hydroxide is 9·1 Cal. less than that of ferrous oxide to ignited ferric oxide. Ferrous oxide does not appear to be a polymer. If it is then the heat of formation of Fe_2O_3 in $Fe_2O_3.3H_2O$ is less than 183·2 Cal. The heat of formation of intensely-heated ferric oxide is 192·2 Cal.; that of the oxide in precipitated hydroxide is 183 Cal. The difference between these values, 9 Cal., is the heat of polymerization, while 5·5 Cal. was derived from ferric hydroxide that had been heated to 160°. These approximate results accord with the views of different investigators that ferric oxide under various conditions forms complex molecules. Berthelot†, from a study of ferric acetate, concluded that "l'oxyde de fer, un fois séparé des acides, prend certains états moléculaires nouveaux comparable à une condensation polymérique . . ." Wyroubouf and Verneuil‡ consider that very complex molecules of ferric oxide exist. The decreasing solubility in acid of the hydroxide as the water content of it falls is undoubtedly due to formation of complex molecules.

Attention is called to the statement made by other investigators and the writer§ that the heat effect of each of the three atoms of oxygen in ferric oxide is the same and that the heat of formation of ferric oxide at high temperatures is about three times that of ferrous oxide. Since, however, part of the heat is due to the formation of complex molecules of ferric oxide, the heat effect of the third atom of oxygen is considerably less than that of the first atom. Therefore, the union of oxygen with iron conforms to the rule that the second, third or fourth atom of an element combining gives less heat effect than the first one.

The term ferric *hydroxide* has been used for convenience in this paper regardless of the question whether definite hydrates of ferric oxide exist. Foote and Bradley‖ have shown that in the hydrated oxides of iron occurring as minerals there is no

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* This Journal, xxxvi, 55, and Zs. anorg. Chem., lxxxiii, 97.

† Ann. Chem. Phys. [3], lxv, 177, 1862.

‡ Bull. Soc. Chem. [3], xxi, 137, 1899.

§ Loc. cit.

‖ This Journal, xxxvi, 184, 1913.

simple molecular ratio between the water and the ferric oxide. Furthermore, Professor Foote, in an investigation which will be published later, has found that part of the water in ferric hydroxide, precipitated and washed at common temperature, behaves in freezing like capillary water.

Titanium Dioxide.—Titanium hydroxide precipitated by ammonia, dried at 100°, contained 6·7 per cent of water, and after heating for a day at about 160°, 5 per cent. It was finally heated three days to 225–240°, losing the last day less 0·1 per cent. The preparation lost on ignition in two determinations 2·23 and 2·24 per cent. The results of fusion with sodium peroxide were 702 and 688, mean 695 cal. for the heat effect of 1 g. of the substance containing 0·978 g. of TiO_2 and 0·022 g. of water. Assuming that the water content reacts in the fusion as free water, we have

$$695 - (0{\cdot}022 \times 2000) \div 0{\cdot}978 = 666 \text{ cal.}$$

The heat effect of ignited titanium dioxide was found* to be 629 cal. Hence $(666 - 629) \times 80 = 3{\cdot}0$ Cal. for the heat effect of the condensation of titanium on ignition. If it be assumed that the heat of union of water with titanium dioxide equal the heat effect of $Na_2O + H_2O$ the result is 6·0 Cal. Hence titanium dioxide, holding 2·2 per cent of water at about 240°, evolves between 3 and 6 Cal. on ignition.

Silica.—Silicic acid was made by adding hydrochloric acid to a solution of sodium silicate and evaporating to dryness on a steam bath. After washing and drying it was heated a day at 360–400°. The preparation contained 3·8 per cent of water. Two determinations of the heat effect of 1 g. fused with sodium peroxide gave 1268 and 1207, mean 1237 cal. Some years ago I found for ignited silica 1185 and 1182, mean 1183 cal. These values indicate that silica polymerizes at high temperatures with small heat effect.

Zinc Oxide.—De Forcrand† made a thorough investigation of zinc oxide. His results for the heat of formation of the oxide prepared at increasing temperatures are 80·29, 82·98, 84·50 and 84·70 Cal.

In conclusion, attention is called to the uncertainty in the derived heats of combination of water with the oxides of the heavy metals given in the following table:

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* This Journal, xxvii, 393.

† Ann. Ch. Phys. (7), xxvii, 26, 1902.

	$R + O + H_2O$*	$R + O = RO$ (amor.)	$RO + H_2O$
Zn	82·7	80·3†	2·4 Cal.
Cd	65·7	§§57 ‡	8·7
Mn	94·8	90·8§	4·0
Fe	68·3	§§64·3‡	4·0
Co	63·4	50·5	12·9

* Thomsen. † De Forcrand, loc. cit. ‡ This Journal, xxxvi, 55, 1913.
§§ Ibid., xxx, 193, 1910. § LeChatelier, C. R., cxxii, 81.

Thomsen derived the heat of formation of the hydroxide of a heavy metal from the heat effect when the metal is dissolved in a dilute acid and the heat of neutralization of the hydroxide of the metal by the acid. Hence the hydroxide may be regarded as formed by the union of water with unpolymerized molecules of oxide. The derived values for $ZnO + H_2O = 2·4$, $MnO + H_2O = 4·0$, $FeO + H_2O = 4·0$ may be low since the heats of formation of the oxides may include a small heat effect due to polymerization at high temperatures. The value $Cd + O = 57$ is regarded only as an approximation and hence the same is said of $CdO + H_2O = 8·7$. The value $CoO + H_2O = 12·9$ is undoubtedly too large. There is an error in the data from which it is derived.

Art. III.—A *Study of the Relations existing between the Chemical, Optical and other Physical Properties of the Members of the Garnet Group*; by W. E. Ford.

It is well recognized that one of the important mineralogical problems at present demanding solution is the establishment of the relations that exist between the chemical composition of a mineral and its physical properties. No one doubts but that a definite relationship does exist between them since that fact has been abundantly proved in various isolated cases. The complexities of the general problem are, however, so great and the exact data at hand so limited that as yet it has been impossible to give any satisfactory statement of the relations involved. One attempt has been made in the so-called Gladstone Law to correlate the chemical composition of a mineral with its index of refraction, specific gravity and molecular weight. In certain cases the assumptions of this law gave reasonably close results, but in others the discrepancies were very great. The Gladstone Law ignored any possible influence that the physical structure of the molecules and the crystal net-work in which they are grouped might have upon the physical properties. That such molecular characters do influence the physical properties of a mineral is proven by their variation in the different cases of polymorphism. It is very probable that any law that would correlate the chemical and physical properties of the minerals belonging to one crystal system would have to be modified in order to apply it to another system. Further, it would seem also probable that not only the arrangement of the crystal particles in a particular net-work but also the structure of the individual molecule or group of molecules that forms the unit of the net-work would have a definite effect upon the physical properties. In other words, it seems reasonable to suppose that while the chemical composition of a mineral has undoubtedly a predominating influence, its effect is modified by these other factors. Very possibly any general law that may be derived will have to be modified by the inclusion in it of factors that would vary not only for the different crystal systems but also for the different minerals or groups of minerals.

At the present time such considerations as the above are almost purely speculative in nature. Before anything like a satisfactory general statement can be made, a far greater amount of accurate data than at present available must be accumulated as well as the further study and correlation of the facts already known. The present investigation is simply a contribution to the preliminary study of the general problem.

It has seemed to the writer that the study of the isometric minerals would be the natural starting point on the general problem, since in this system the crystal structure has the highest possible symmetry, and that, therefore in the study of isometric minerals, one or more of the factors that might modify the relationships would probably be eliminated. In considering the isometric minerals, the Garnet Group naturally suggested itself first for study. Here we have a series of minerals with widely varying percentage composition, embracing a large number of different elements and furthermore one about which considerable data are already available. The following study of a series of garnets has produced results that go to confirm some of our fundamental assumptions and lead to other interesting speculations.

The literature was searched for reliable analyses of the garnet minerals in conjunction with which indices of refraction were given. After rejecting analyses that showed the presence of unusual radicals like TiO_2, CrO, the alkalies, etc., there remained some twenty-three analyses available. In the case of several of these, where the index of refraction was not given in the original description, it happened that material was obtained upon which the needed determination could be made, either from the Brush Mineral Collection or through the kindness of various correspondents. These analyses, arranged according to the rise in the index of refraction, are given below.

	1	2	3	4	5	6	7	8
Index of refraction	1·7364	1·7412	1·7417	1·7438	1·7504	1·7596*	1·7626	1·7779
Specific gravity	3·506	-----	3·715	3·525	-----	3·837	3·633	4·040
SiO_2	40·79	41·34	43·37	38·80	40·90	41·59	38·12	37·25
Al_2O_3	21·70	22·75	20·99	22·66	22·81	23·13	18·35	19·43
Cr_2O_3	-----	2·96	2·36	-----	1·48	-----	----	----
Fe_2O_3	0·18	-----	-----	1·75	-----	1·90	7·17	3·29
FeO	0·43	12·12	10·21	-----	13·34	15·55	-----	35·45
MnO	1·07	0·36	0·52	0·30	0·38	-----	0·13	1·24
CaO	35·63	5·17	4·54	35·00	4·70	0·92	35·40	2·51
MgO	0·39	16·20	18·42	0·68	16·40	17·23	0·02	1·13
	100·19	100·90	100·41	99·19	100·04	100·32	99·19§	100·30

	9	10	11	12	13	14	15	16
Index of refraction	1·7815	1·7921*	1·7998	1·8008*‡	1·8010*	1·8057*	1·8074*	1·8078
Specific gravity	4·025	4·230	4·058	4·255*‡	4·093	4·169*	4·163	3·960
SiO_2	38·07	35·66	35·76	35·35	39·29	35·65	37·61	37·40
Al_2O_3	19·63	18·55	21·06	20·41	21·70	20·93	22·70	21·08
Cr_2O_3	-----	-----	-----	-----	-----	-----	-----	-----
Fe_2O_3	2·16	0·32	1·78	2·75	-----	-----	----	2·01
FeO	31·58	14·25	-----	1·75	30·82	5·67	33·83	28·49
MnO	1·36	29·48	39·40	38·70	1·51	37·21	1·12	----
CaO	5·03	1·15	1·23	0·94	1·99	0·48	1·44	3·05
MgO	2·77	0·88†	1·46	0·27	5·26	-----	3·61	8·22
	100·60	100·33	99·69	100·17	100·57	99·94	100·31	100·25

	17	18	19	20	21	22	23
Index of refraction	1·8105	1·8132*	1·8200*	1·8384	1·8645*‖	1·8878	1·8884
Specific gravity	4·273	4·135*	-----	3·418	3·781	3·660	3·801
SiO_2	36·16	37·58	37·06	37·11	34·53	36·79	35·37
Al_2O_3	19·76	21·58	21·96	5·88	6·05	1·39	1·54
Cr_2O_3	-----	-----	--- -	22·54	-----	-----	1·32
Fe_2O_3	-----	-----	-----	-----	25·10	29·30	28·89
FeO	11·10	36·69	20·05	2·44	0·84	0·69	0·52
MnO	32·18	-----	20·41	-----	tr.	0·26	0·34
CaO	0·58	1·89	0·08	30·34	33·67	31·40	32·26
MgO	0·22	2·31	tr.	1·10	-----	0·77	0·21
	100·00	100·05	99·56	99·41	100·19	100·60	100·45

* Determination made by Author.
† Composed of Alk. 0·48 and Ign. 0·44.
‡ Determined on material presented by Dr. Geo. F. Kunz.
§ Original anal. gives Na_2O, 0·42; Ign., 0·74; Total, 100·35.
‖ Determined on material presented by Prof. L. Colomba.

1. Grossularite, Xalostoc, Mexico; Seebach, Inaug. Diss., Heidelberg, 1906; Centralbl. Min.. 774, 1906.
2. Pyrope, Kimberley; Fischer, N. Jb. Min., i, 393, ref., 1890; Index of refraction by Wülfing, Mikroskopische Physiographie der petrographisch wichtigen Mineralien by H. Rosenbusch and E. A. Wülfing, p. 18, 1905.
3. Pyrope, Colorado River, Arizona; Seebach, loc. cit.
4. Grossularite, Wakefield, Ottawa Co., Quebec, Canada; Bullman, this Journal, xxvii, 306, 1884; Wülfing, loc. cit.
5. Pyrope, Kimberley. S. Africa; Fischer, loc. cit.; Wülfing, loc. cit.
6. Rhodolite, Mason Branch, Cowee Creek, Macon Co., N. C.; Pratt, this Journal, v, 294, 1898.
7. Hessonite, Ala, Piedmont; Jannasch, N. Jb. Min., i, 120, 1883; Wülfing, loc. cit.
8. Almandite, Ceylon; Seebach, loc. cit.
9. Almandite, Jeypoor; Seebach, loc. cit.
10. Spessartite, Nathrop, Colo.; Eakins, this Journal, xxxi, 435, 1886.
11. Spessartite, Tsilaisina, Madagascar; Duparc, Wunder and Sabot, Les Minéraux des Pegmatites des Environs D'Antsirabé a Madagascar, 404, 1910.
12. Spessartite, Amelia Co., Va.; Clarke, U. S. G. S. Bull. 60, 129, 1890.
13. Almandite, Fort Wrangel, Alaska; Kountze, Dana's System of Mineralogy, 6th Ed., 442, 1892.
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15. Almandite, Salida, Colo.; Penfield and Sperry, this Journal, xxxii, 310, 1886.
16. Almandite, Wittichen; Hebenstreit, Zs. Kr., ii, 104, 1878; Wülfing, loc. cit.
17. Spessartite, Haddam, Conn.; Rammelsberg, Jour. pr. Chem., lv, 487, 1852; Wülfing, loc. cit.
18. Almandite, Redding, Conn.; F. L. Sperry, unpublished analysis from records of Brush Mineral Collection.
19. Spessartite, Pala, San Diego, Cal.; Schaller. Published by permission of the Director of the U. S. Geological Survey.
20. Uvarovite, Bissersk, Ural Mts.; Iddings, Rock Minerals, 360, 1906; Wülfing, loc. cit.
21. Andradite, Fluminimaggiore; Serra, Rend. R. Accad. Sci., Napoli, 222, 1910.
22. Andradite, Dognaczka; Seebach, loc. cit.
23. Demantoid, Polewski-Zawod; Seebach, loc. cit.

These analyses were subjected to the following calculations: The molecular ratios were obtained from each analysis; the discrepancies between these numbers and theory were averaged and from these new values the analyses were recalculated and then reduced to a 100 per cent summation. This was done in order that the unavoidable errors of analysis should be equally distributed over the various garnet molecules present and not concentrated in the subsequent calculations upon a single molecule, as would otherwise have been the case. From the analyses modified in this way the percentages of the molecules corresponding to the different garnets present were derived. Then these results were tabulated according to increasing indices of refraction and a careful study made of them in order to discover the part each garnet molecule played in determining the index of refraction of each combination. The assumption was made that it would be found in this series, as has been proved in a number of other cases, that the index of refraction of each specimen would have a direct relationship to the indices of refractions of the component garnet molecules and to the percentage of each in the whole. None of the analyses gave the theoretical composition of any one of the different members of the garnet group, but in a few cases, namely analyses 1, 4, 11, 12, 22 and 23, they approached closely to theory. In no case, therefore, would the index of refraction be exactly equal to that of a single garnet but would always be derived from the influence of the presence of at least two different garnet molecules. But by a study of this table tentative values were assigned to the indices of refraction of the individual garnets and then from these assumptions theoretical values for the indices of refraction were calculated for each analysis. From the results obtained it was possible to discover in what regard the original assumptions were in error and how to modify them in order to bring the measured and calculated values into closer accord. After several attempts of this kind assumptions were made which gave in the large majority of cases a very close agreement between the measured and calculated values. These results are given in the table on page 37. As under the ordinary conditions a determination of the refractive index of a mineral can hardly be considered accurate beyond the third place of decimals, the measured and calculated values of the indices are not given beyond this point. In fact the chances are, that in the majority of these determinations, the measured values are accurate only to ± ·002. The discrepancy in each case between the measured and calculated values is given in the last column under the heading error. It will be noted that this discrepancy is, in about half of the cases, within the probable limit of error in the observations, and that it does not materially exceed this amount except in four cases, namely in analyses 2, 8, 9 and 10. In these four cases the discrepancy is large, but considering the close agreement shown in all the other cases it would seem as if there must be some explanation to account for the variation in these particular cases and that they ought not to carry much weight against the accuracy of the assumptions upon which the table was made. The average discrepancy between the calculated and observed values for the entire series is only ·007, and if the four cases mentioned above are omitted this is reduced to ·0027. From this table, therefore, it becomes evident that the indices of refraction of the members of the garnet group vary directly with the variation in the composition and that the theoretical values assumed for the indices of the different simple garnets are very closely correct. Such close agreements in such a large series of cases could hardly be accounted for on any other assumption.

Analysis	Pyrope	Grossularite	Spessartite	Almandite	Uvarovite	Andradite	*n*, meas.	*n*, calc.	Error
Pyrope	100.00	----	----	----	----	----	----	1·705	----
Grossularite	----	100·00	----	---	----	----	----	1·735	----
1	1·29	94·66	2·49	0·99	----	0·57	1·736	1·738	+·002
2	55·30	5·96	0·75	28·83	9·16	----	1·741	1·759	+·018
3	61·66	5·31	1·15	24·04	7·48	----	1·742	1·742	·000
4	2·12	91·93	0·69	----	----	5·26	1·744	1·743	—·001
5	54·78	8·61	0·88	30·99	4·74	----	1·750	1·755	+·005
6	57·53	----	----	36·77	----	5·70	1·760	1·762	+·002
7	----	79·19	0·30	----	----	20·51	1·763	1·768	+·005
8	2·12	----	3·01	85·09	----	9·78	1·778	1·833	+·055
9	9·33	7·68	3·16	72·96	----	6·87	1·782	1·815	+·033
10	----	1·93	65·42	31·37	----	1·11	1·792	1·806	+·014
11	3·57	----	91·29	----	----	5·14	1·800	1·801	+·001
Spessartite	----	----	100·00	----	----	----	----	1·800	----
12	----	----	93·66	3·63	----	2·71	1·801	1·804	+·003
13	17·97	5·39	3·61	73·03	----	----	1·801	1·801	·000
14	----	1·25	85·77	12·98	----	----	1·806	1·803	—·003
15	12·40	4·03	2·71	80·76	----	----	1·807	1·807	·000
16	26·90	2·47	----	64·39	----	6·42	1·808	1·802	—·006
17	0·67	1·48	72·59	25·26	----	----	1·811	1·806	—·005
18	7·88	5·21	----	86·91	----	----	1·813	1·815	+·002
19	----	0·22	50·44	49·34	----	----	1·820	1·815	—·005
Almandite	----	----	----	100·00	----	----	----	1·830	----
20	3·75	17·33	----	5·76	73·16	----	1·838	1·838	·000
21	----	23·11	----	1·78	----	75·11	1·865	1·857	—·008
Uvarovite	----	----	----	----	100·00	----	----	1·870	----
22	2·57	1·15	0·65	1·59	----	94·04	1·888	1·887	—·001
23	0·69	4·06	0·79	1·19	4·18	89·09	1·888	1·885	—·003
Andradite	----	----	----	----	----	100·00	----	1·895	----

If then the garnets were composed of but two isomorphous molecules it would be possible, after determining through qualitative tests which two molecules were present, to establish the composition of the specimen by means of its refractive index. Unfortunately, however, the majority of garnets contain three or more isomorphous molecules. It would be possible, therefore, in any series composed of three different molecules to have considerable variation in composition without changing the index of refraction. The problem would be still further complicated if four different molecules were present.

The problem in the case of a garnet containing three different molcules is simplified by the fact, recently pointed out by Boecke,* that the miscibility of the different garnets with each other has definite limits. In any series only a certain restricted portion of the possible combinations are found. The results of Boecke's investigation were not given, however, in a form that made them available for the present discussion, so it became necessary to make an independent study along similar lines.

All the readily available garnet analyses were collected and studied. All analyses were rejected which contained unusual elements or molecules, the study being confined to the five common members of the group, namely, pyrope, grossularite, spessartite, almandite, and andradite. Further, any analysis which on calculation did not show a reasonably close agreement to the theoretical garnet formula was discarded. There remained after such elimination nearly two hundred analyses available for study. The percentages of the different components in each of these garnets were obtained and tabulated.

It was found that nearly 15 per cent of the total number contained four or more constituents, with the molecule in smallest amount forming more than 5 per cent of the total. The remaining 85 per cent were garnets in which two or three components formed more than 95 per cent of the total. Nearly 17 per cent of all the analyses studied had but two constituents. In other words, approximately 60 per cent of all garnets contain three isomorphous molecules which together form more than 95 per cent of the total constituents. Of the garnets containing three constituents the average percentage of the molecule present in smallest amount was 4·7. The highest percentage observed of the third molecule was 20 and 86 per cent of these garnets show the third molecule forming less than 10 per cent of the total. It is evident, therefore, that in any given series formed by the mixture of three garnet molecules, two of them must predominate while the third is present in very subordinate amounts.

Interesting data concerning the frequency of occurrence of the different possible combinations were available. Of the 31 garnets containing but two components the following combinations were observed: grossularite + andradite = 14; alman-

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* Zs. Kr., liii, 149, 1913.

dite + spessartite = 7; almandite + andradite = 4; grossularite + pyrope = 3; almandite + pyrope = 1; almandite + grossularite 1; andradite + spessartite = 1; grossularite + spessartite = 0; pyrope + spessartite = 0. Of the possible different combinations with three constituents the following were observed: grossularite + andradite + almandite = 28; grossularite + andradite + pyrope = 25; grossularite + andradite + spessartite = 15; grossularite + almandite + pyrope = 15; grossularite + almandite + spessartite = 13; pyrope + almandite + andradite 10; pyrope + almandite + spessartite = 7; andradite + almandite + spessartite = 6; andradite + pyrope + spessartite = 2.

The question naturally arises in this connection, whether this limited miscibility of the different garnet molecules depends upon inherent characteristics of the garnet group and that in a certain case only a definite amount of one molecule can combine with another, or whether it is brought about by the natural restrictions of the ordinary mode of occurrence of that garnet. In other words, this limited miscibility may not depend upon chemical restrictions, but rather upon restrictions imposed by the conditions of the origin of the garnets. This is a very interesting question and might possibly find its solution in either of two ways. It might be possible to make experimental mixtures of the different garnet molecules in all proportions and determine the limits, if any, of their miscibility. Another method would be to make an exhaustive study of the modes of occurrence of the members of the group, together with their associations, etc. From this latter method it would probably be possible to discover whether or not the manner of origin of the garnets had such a positive influence upon their composition.

In addition to the above study of the variation of the refractive index with change in the chemical composition, a similar study of the relations between the specific gravity and composition was made. Of the analyses studied, the specific gravity of the specimen was recorded in 72 cases. Three of these analyses were rejected because of obvious errors. In five other cases the error between the observed and calculated specific gravities was greater than 0·1. These five analyses were also rejected, leaving 64 analyses upon which the calculations were based. After considerable experimenting it was found that the following specific gravity values were most satisfactory: pyrope = 3·510; grossularite = 3·530; andradite = 3·750; spessartite = 4·180, and almandite = 4·250. By the use of these values the theoretical specific gravity of each of the 64 garnets was calculated from its analysis. The average difference between the measured and calculated specific gravities of the series was found to be 0·045 or, if the plus and minus signs were taken into consideration, it was only +0·002. From this it would seem as if the values assigned above to the specific gravities of the various pure garnets were at least very nearly correct.

Figures 1 to 8 show the facts outlined above in graphical form by means of equilateral triangular plotting. The black dots represent the positions on the charts of the different analyses containing two or three constituents. The heavy broken lines indicate the probable limits of the possible mixtures of each series. The heavy solid lines give the loci of points representing the different mixtures possible with a certain index of refraction. The lighter solid lines show in a like manner the mixtures possible with a given specific gravity. Therefore, if the refractive index and specific gravity of a garnet are known, together with its chief components as determined by qualitative tests, it ought to be possible in the majority of cases to predict rather closely what its chemical composition should be.

A further study was made of the analyses quoted on page 34 and 35 to discover, if possible, any interrelationships between the indices of refraction, specific gravities and molecular weights. The garnets, the specific gravities of which were unknown, were naturally omitted from consideration. Analysis 20 was also eliminated because of the small amount of data available concerning the uvarovite molecule. The results of this study are given in the table below and are also shown in a graphical form in figs. 9 to 12.

Analysis	n.	Sp.Gr.	$\frac{n-1}{G}$	Mol. Wt.	$\frac{F}{G}$	$\frac{R}{G}$
Pyrope	1·705	3·510	·2008	404·5	·240	5·914
Grossularite	1·735	3·530	·2082	451·7	·227	6·196
1	1·736	3·506	·2099	453·0	·228	6·249
3	1·742	3·715	·1997	436·6	·213	5·959
4	1·742	3·525	·2104	454·0	·224	6·280
6	1·760	3·837	·1980	445·3	·200	5·970
7	1·763	3·633	·2100	463·6	·210	6·316
8	1·778	4·040	·1925	498·0	·184	5·826
9	1·781	4·025	·2100	487·3	·184	5·878
10	1·792	4·230	·1925	495·9	·170	5·698
11	1·800	4·058	·1940	493·8	·176	6·019
Spessartite	1·800	4·180	·1904	496·4	·171	5·843
12	1·801	4·255	·1882	496·8	·168	5·750
13	1·801	4·093	·1957	479·4	·188	5·977
14	1·806	4·169	·1933	496·2	·170	5·917
15	1·807	4·163	·1938	484·9	·170	5·935
16	1·808	3·960	·2040	474·0	·179	6·250
17	1·810	4·273	·1895	495·8	·165	5·812
18	1·813	4·135	·1966	486·4	·169	6·035
Almandite	1·830	4·250	·1952	499·1	·161	6·039
21	1·864	3·803	·2271	495·7	·170	7·132
22	1·888	3·660	·2425	505·7	·170	7·701
23	1·888	3·801	·2336	505·4	·163	7·415
Andradite	1·895	3·750	·2386	509·3	·164	7·600

FIG. 1.

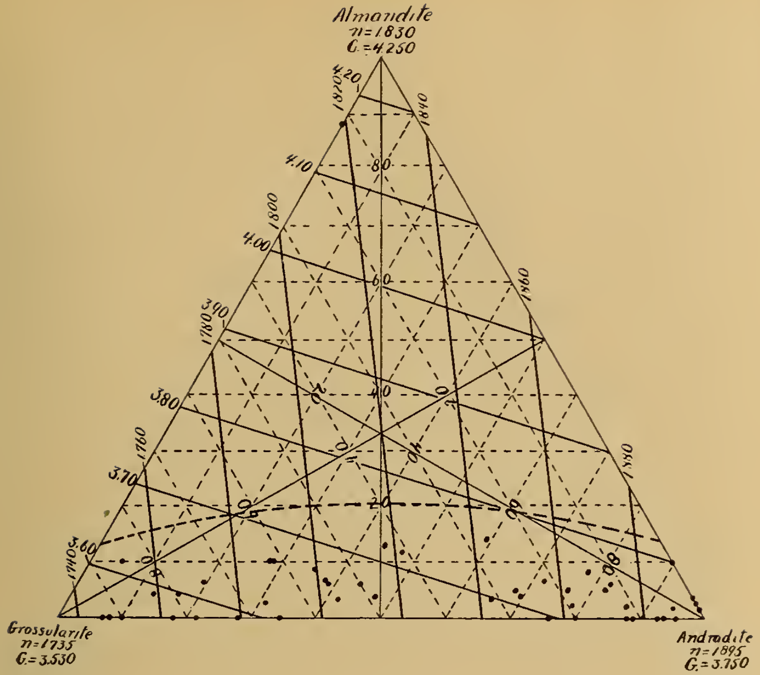

Almandite
n=1.830
G.=4.250
Grossularite
n=1.735
G.=3.530
Andradite
n=1.895
G.=3.750
4.20
4.10
4.00
3.90
3.80
3.70
3.60
1820
1840
1800
1780
1760
1740
1860
1880
80
60
40
20

FIG. 2.

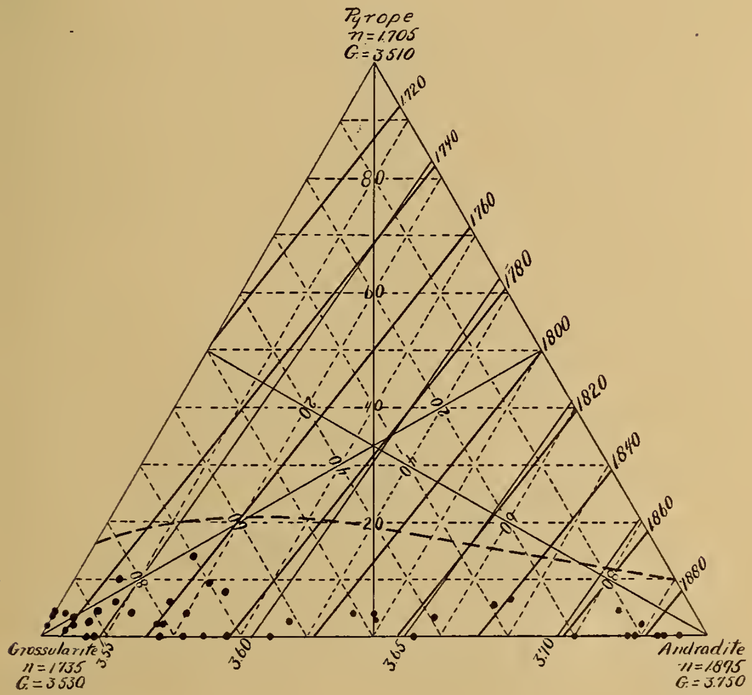

Pyrope
n=1.705
G.=3.510
Grossularite
n=1.735
G.=3.530
Andradite
n=1.895
G.=3.750
1720
1740
1760
1780
1800
1820
1840
1860
1880
80
60
40
20
3.55
3.60
3.65
3.70

Fig. 3.

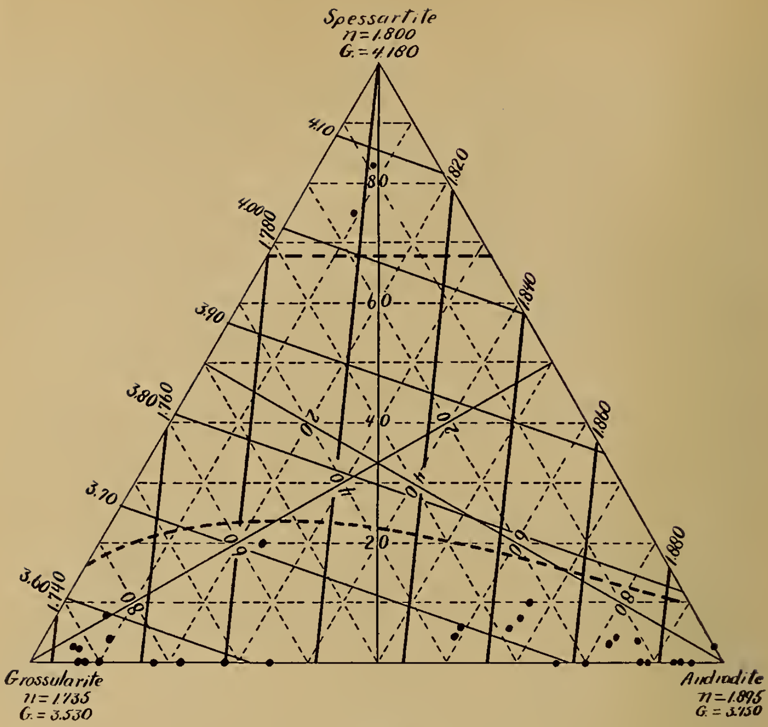

Spessartite
n=1.800
G.=4.180
4.10
1.820
80
4.00
1.780
1.840
3.90
60
3.80
1.760
40
1.860
3.70
20
3.60
1.740
1.880
Grossularite
n=1.735
G.=3.530
Andradite
n=1.895
G.=3.750

Fig. 4.

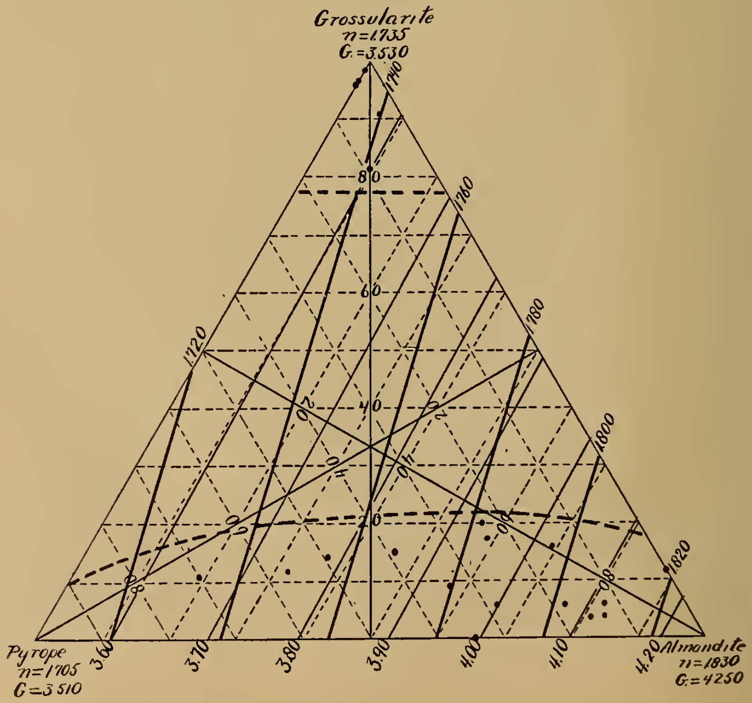

Grossularite
n=1.735
G.=3.530
1.740
80
1.760
60
1.780
1.720
40
1.800
20
1.820
Pyrope
n=1.705
G=3.510
3.60
3.70
3.80
3.90
4.00
4.10
4.20
Almandite
n=1.830
G.=4.250

FIG. 5.

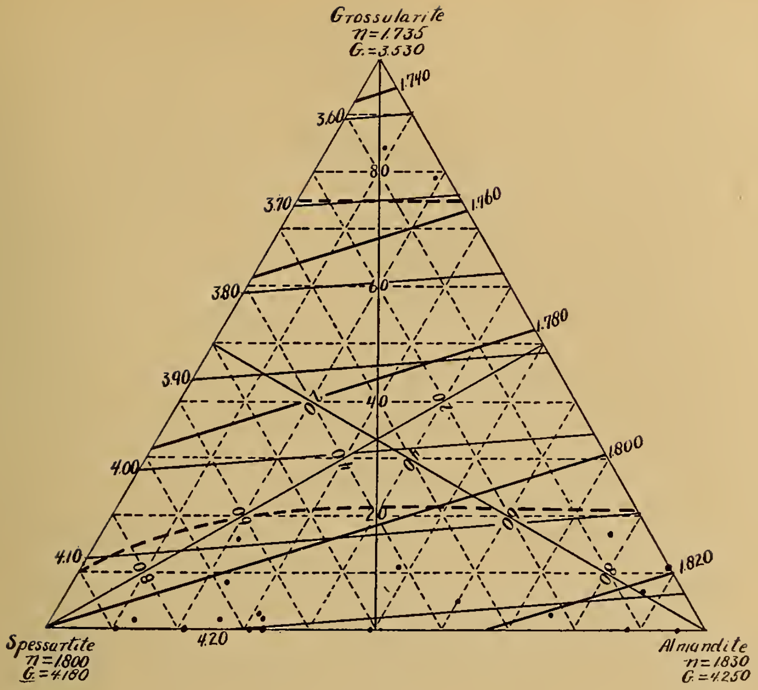

Grossularite
n=1.735
G.=3.530
1.740
3.60
80
3.70
1.760
3.80
60
1.780
3.90
20
40
20
4.00
1.800
40
40
60
20
60
4.10
80
80
1.820
4.20
Spessartite
n=1.800
G.=4.180
Almandite
n=1.830
G.=4.250

FIG. 6.

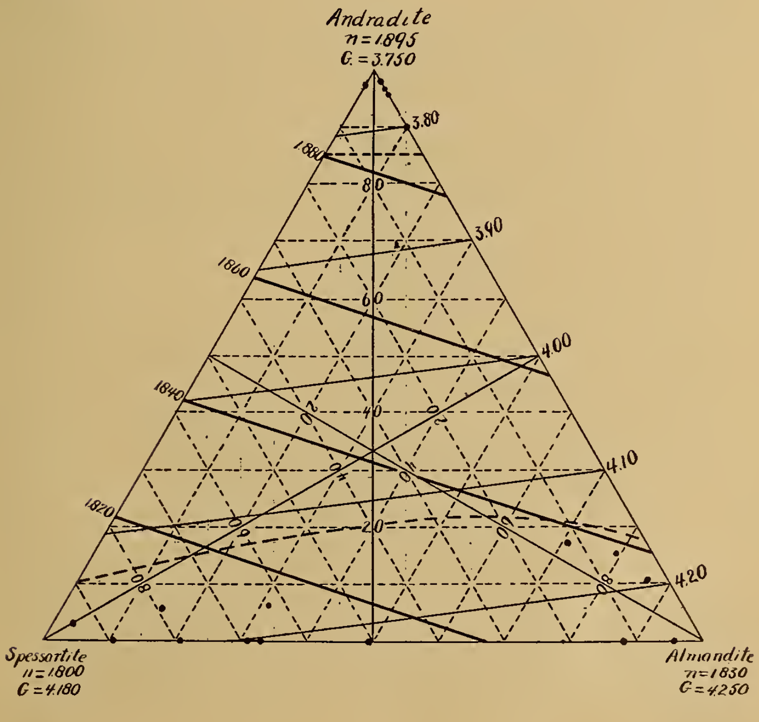

Andradite
n=1.895
G.=3.750
3.80
1.880
80
3.90
1.860
60
4.00
1.840
20
40
20
40
40
4.10
1.820
60
20
60
80
80
4.20
Spessartite
n=1.800
G=4.180
Almandite
n=1.830
G=4.250

FIG. 7.

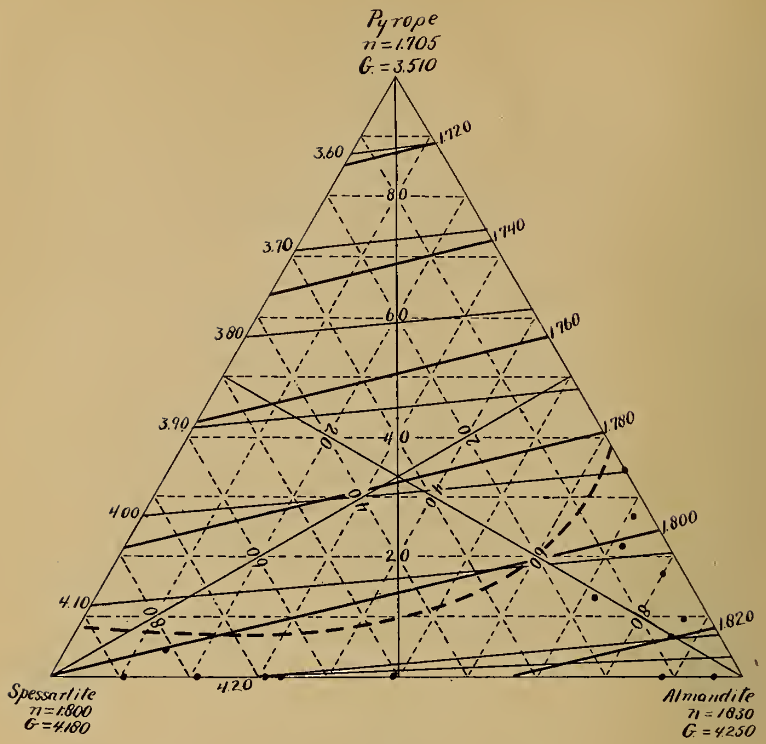

Pyrope
n = 1.705
G. = 3.510
1.720
3.60
80
1.740
3.70
60
3.80
1.760
3.90
20
40
20
1.780
4.00
40
40
60
1.800
20
60
4.10
80
80
1.820
4.20
Spessartite
n = 1.800
G = 4.180
Almandite
n = 1.830
G. = 4.250

FIG. 8.

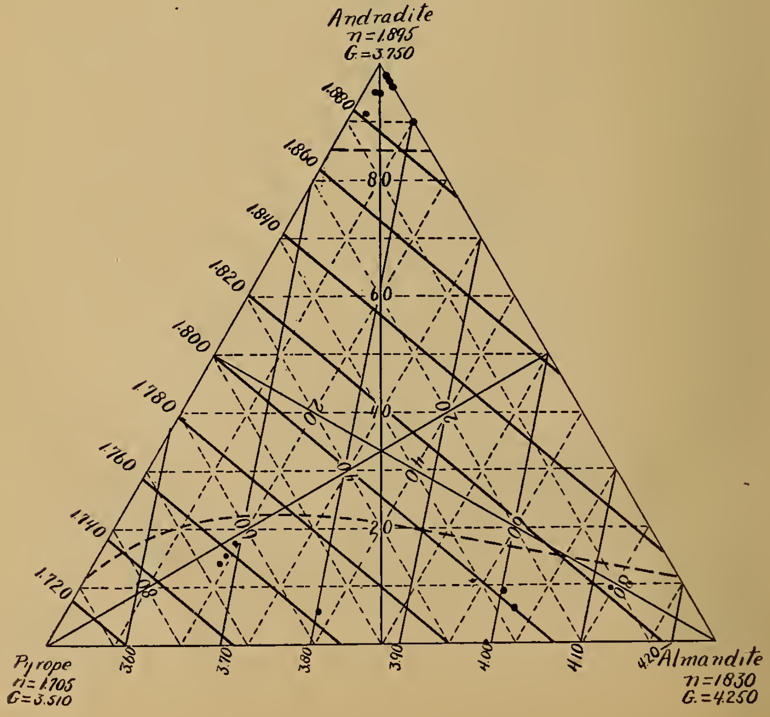

Andradite
n = 1.895
G. = 3.750
1.880
1.860
80
1.840
1.820
60
1.800
1.780
20
40
20
1.760
40
40
1.740
60
20
60
1.720
80
80
Pyrope
n = 1.705
G = 3.510
3.60
3.70
3.80
3.90
4.00
4.10
4.20
Almandite
n = 1830
G. = 4250

FIG. 9.

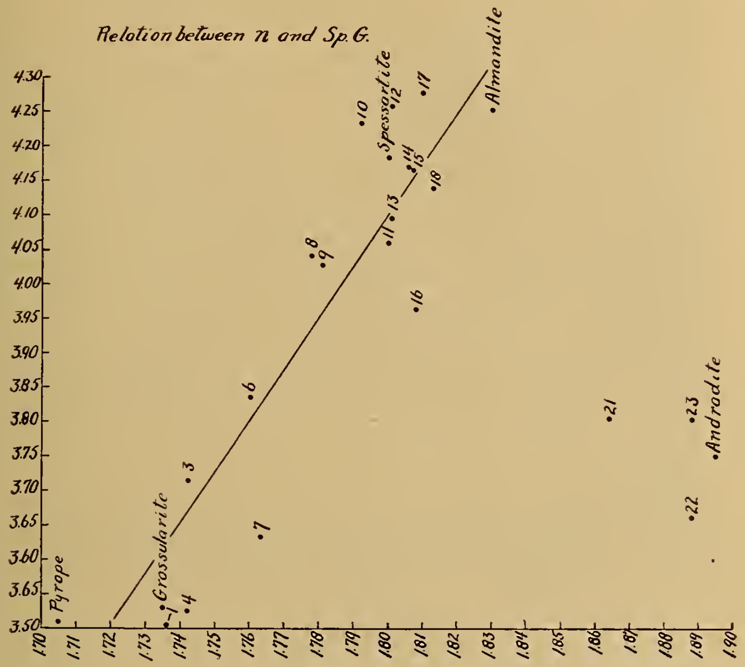

Relation between n and Sp. G.
4.30
4.25
4.20
4.15
4.10
4.05
4.00
3.95
3.90
3.85
3.80
3.75
3.70
3.65
3.60
3.65
3.50
1.70
1.71
1.72
1.73
1.74
1.75
1.76
1.77
1.78
1.79
1.80
1.81
1.82
1.83
1.84
1.85
1.86
1.87
1.88
1.89
1.90
Pyrope
Grossularite
Spessartite
Almandite
Andradite
1
3
4
6
7
8
9
10
11
12
13
14
15
16
17
18
21
22
23

FIG. 10.

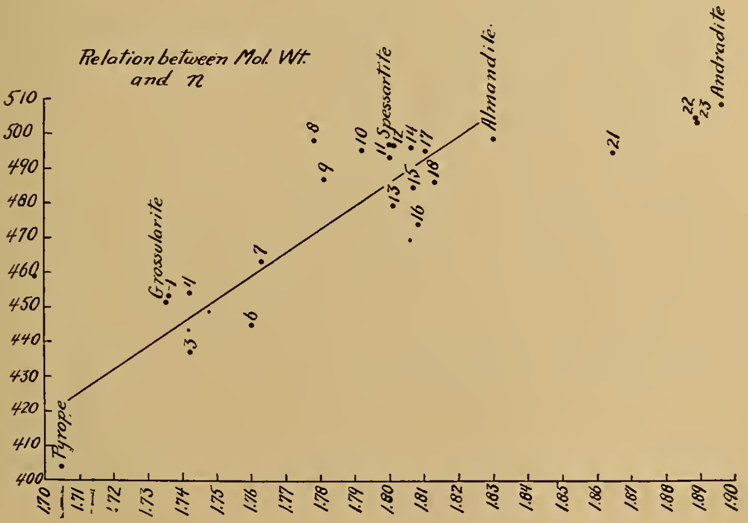

Relation between Mol. Wt. and n
510
500
490
480
470
460
450
440
430
420
410
400
1.70
1.71
1.72
1.73
1.74
1.75
1.76
1.77
1.78
1.79
1.80
1.81
1.82
1.83
1.84
1.85
1.86
1.87
1.88
1.89
1.90
Pyrope
Grossularite
11 Spessartite
Almandite
Andradite
1
3
6
7
8
9
10
12
13
14
15
16
17
18
21
22
23

FIG. 11.

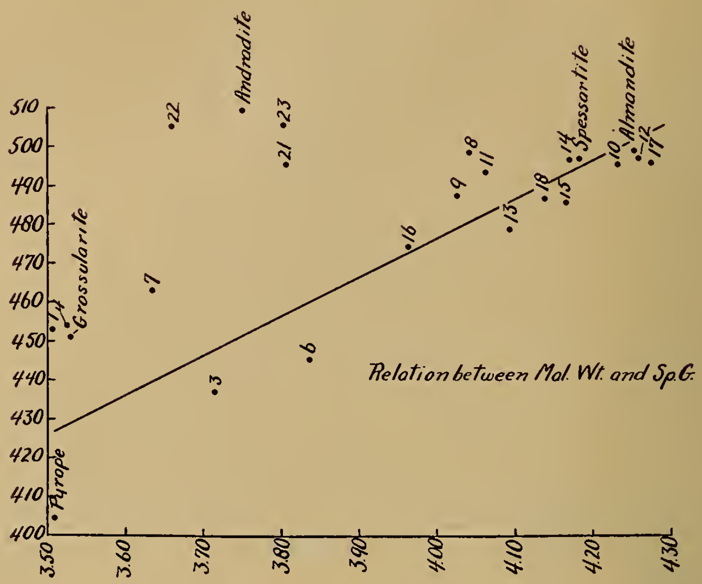
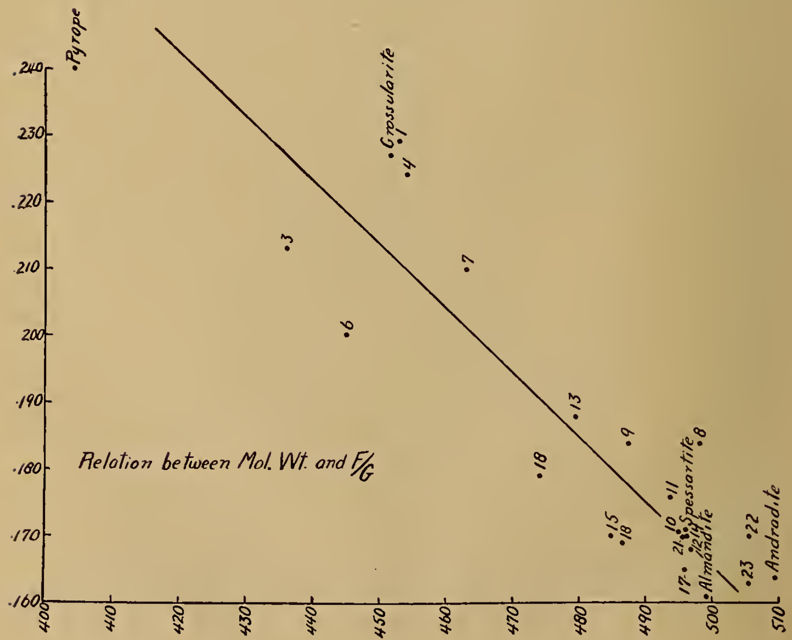

Relation between Mol. Wt. and Sp.G.
510
500
490
480
470
460
450
440
430
420
410
400
3.50
3.60
3.70
3.80
3.90
4.00
4.10
4.20
4.30
Pyrope
Grossularite
Andradite
Spessartite
Almandite
1
4
7
22
3
6
21
23
16
9
8
11
13
18
15
14
10
12
17

FIG. 12.


Relation between Mol. Wt. and F/G
.240
.230
.220
.210
.200
.190
.180
.170
.160
400
410
420
430
440
450
460
470
480
490
500
510
Pyrope
Grossularite
Andradite
Spessartite
Almandite
1
4
3
6
7
13
9
8
18
11
15
18
10
21
22
14
17
23
22

In the first column of the table (p. 40) are given the indices of refraction of the different garnets arranged in an ascending series. The second column gives the corresponding specific gravities. It is seen that in a general way the specific gravity increases with rise of the refractive index, although this correspondence between the two is by no means constant. There is, moreover, a sharp break in the continuity beginning at analysis 21. It is evident from this that garnets which contain large amounts of the andradite molecule show decidedly different relations between these two properties than the other garnets. This is readily seen when the fact is noted that andradite with the highest refractive index of all the garnets has a specific gravity lower than either spessartite or almandite. The relations between the refractive indices and specific gravities for the series is shown in fig. 9.

In the third column of the table are given the figures obtained by use of the constant K of the Gladstone Law, which equals $\frac{n-1}{\mathrm{G.}}$. The results here were reasonably concordant until the garnets containing the andradite molecule were reached. These naturally showed a distinct variation. Taking the average of the numbers obtained from the analyses through almandite we obtain as a mean value, $\mathrm{K} = {\cdot}1986$. The average variation from this mean is ·0064 or one of 3·2 per cent. From the above it is seen that with the exception of andradite the members of the garnet group show reasonably constant relations between specific gravity and refractive index.

The fourth column of the table gives the molecular weights of the various garnets as determined from the percentages of each molecule present in them. In general it is seen that the indices of refraction and the molecular weights of the series through almandite increase together. It is also evident that the molecular weights and specific gravities have similar relations. From figures 10 and 11, it is seen, however, that these relationships are not very exact.

Rosicky* has recently briefly discussed the relations between refractive index and specific gravity in minerals and has suggested new formulas for use. He makes use of what he terms (1) the measure of the optical elasticity and (2) the measure of the strength of the refraction. For the measure of the optical elasticity he derives the cubical content of the Fresnel ellipsoid. In the case of an isometric mineral this becomes a sphere and the constant, designated as F, becomes $\frac{4\pi}{3n^3}$ ($n =$ refractive index). This expression divided by the specific

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* Bull. Acad. Sc. Bohême, 1911.

gravity yields what is termed the specific elasticity. In general he finds that the value of the specific elasticity decreases with increase of molecular weight. The column of the table headed $\frac{F}{G}$ gives the values derived in this way for the garnets. In general they follow the rule given above. The variation of the two is not as regular as might be desired. Their relations are shown graphically in fig. 12.

His second formula involves the use of the cubical content of the optical indicatrix. In the case of the isometric minerals this becomes $\frac{4}{3}\pi n^3$, denoted by the symbol R. The quotient $\frac{R}{G}$ is known as the specific refractive power. In general it is found that this value is a constant for a given group of minerals. The column headed $\frac{R}{G}$ gives these values for the garnets studied. Like the values derived from the Gladstone Law they are reasonably constant until the andradite molecule predominates, when there is a sharp break. The mean of these values including all analyses up to number 21 is 5·993. The average variation from this number is 0·135 or a discrepancy of 2·2 per cent.

Conclusions.—From this study of the minerals of the Garnet Group it is definitely established that the index of refraction and specific gravity of any garnet depend in a direct and simple way upon its chemical composition. Further, having given these physical constants of a garnet and knowing from qualitative tests the predominant molecules present, it should be possible in the majority of cases to predict within reasonable limits the composition of the mineral. When the relationships between specific gravity, refractive index and molecular weight are studied they are seen to be fairly constant until the andradite molecule becomes prominent. This causes a distinct break in the continuity of these relations. That the relations between refractive index, specific gravity and molecular weight of andradite is distinctly different from that prevailing in the other garnets is unquestionable. Although there are only a few analyses of andradite available with which the refractive index is given, there are a considerable number of analyses with which the specific gravity is given. To show this variation in the case of andradite it is only necessary to remember that andradite has the highest molecular weight of all the garnets, and then to compare the specific gravities for andradite as quoted by Dana in connection with the analyses on page 443 of the System of Mineralogy with the decidedly higher values given with analyses of almandite and spessartite on the preceding pages of that book. While the relationship between specific gravity and refractive index is often a reasonably definite one, there are apparently frequent exceptions to the rule which at present do not admit of explanation. It is only by the accumulation of large amounts of data concerning these relationships in minerals that we can hope eventually to be able to make a satisfactory statement of the principles involved.

Mineralogical Laboratory of the Sheffield
Scientific School of Yale University,
New Haven, Conn., Dec. 1st, 1914.

Art. IV.—*The Lower Ordovician* (*Tetragraptus Zone*) *at St. John, New Brunswick, and the New Genus Protistograptus*; by F. H. McLearn.

(Contributions from the Paleontological Laboratory, Peabody Museum, Yale University, New Haven, Connecticut, U. S. A.)

In the summer of 1913, during the meetings of the Twelfth International Geological Congress, held in Canada, the members of the A1 Excursion, under the leadership of Doctor G. A. Young, were permitted to see the intricate geology of the city and environs of St. John, New Brunswick. Fossils were collected by members of the party from the Cambrian, Ordovician and Carboniferous formations, but as those of the oldest period are well known to geologists through the long labors of Doctor G. F. Matthew, Professor Charles Schuchert devoted more time to the Ordovician which yields the graptolites. Because of the great stratigraphic value of these fossils, another and larger collection was made by Professor Schuchert and the writer in the spring of 1914 at the same place. All of this material has been studied in the Paleontological Laboratory at Yale University, by the writer, under the direction of Professor Schuchert, and the results are presented below.

The faunas of the St. John Group are familiar to all paleontologists. The life record opens with the provincial Protolenus fauna. The widespread Paradoxides fauna of Middle Cambrian time follows, which at certain horizons is very abundant, although the trilobites are fragmental. Higher occurs the

Johannian, a thick series of cross-bedded sandstones, with worm burrows and broken Lingulellas; the age is probably Upper Cambrian. On the sandstones lie the black slates of the Bretonian, which Matthew divides into four zones. *Dictyonema flabelliforme* Eichwald appears in the second band, *b*, and attains its full development in the band *c*. The fourth zone, *d*, contains a Tetragraptus-Didymograptus fauna, a consideration of which is the object of the present paper.

Location.—Our knowledge of this fauna dates from 1891, when Matthew found graptolites in the black slates at the Suspension Bridge, just below the Reversing Falls. It is interesting to note that this is the only known outcrop of the zone in the Maritime Provinces (which of course excludes Quebec localities). The fossils occur in nearly vertical beds on the north shore of St. John harbor, a short distance below the bridge.

Lithology.—The rock is a black, fissile, very fine-grained, carbonaceous slate. It is very slightly calcareous, due in part to the presence of articulate brachiopods. Matthew (1892*b*) mentions the presence of calcareous nodules, but none have been seen by the writer. Pyrite occurs in joint planes, replacing the orthoids in part and occasionally the graptolites.

The weathered rock cleaves into paper-thin layers, and, owing to the fact that the bedding and the cleavage coincide, the graptolites are preserved in the surfaces of these layers. Gypsum is present in the cleavage planes in very small crystals.

Structural Relations.—About 35 feet of the slates are exposed in the cliff, below the bridge, where they dip to the south at a high angle under the waters of the harbor. On the north, the formation is bounded by a fault (Matthew 1891, p. 128; Young 1913, p. 386) which brings it against the Johannian sandstones and thus obscures the relationship of the Tetragraptus zone to the older formations. It follows that both the upper and lower limits of the Tetragraptus zone at St. John are unknown, and the field relations contribute but little to the determination of their age.

The structure, at this locality, has never been clearly defined. Matthew (1891, p. 128) states that "in this section (at the western end of the city) the whole series of the St. John Group is overturned, and the oldest beds appear uppermost." In a figure (1891, p. 128) the beds of division 3*d* are shown to be overturned. This author, however, notes that the Johannian beds north of the fault "are not overturned, but belong to the northern side of a syncline." Young (p. 386) considers that "the Ordovician measures are the highest preserved members of an overturned syncline," but does not define this syncline further. In the following pages, faunas from two separate horizons are described, and the higher is shown to be of somewhat younger time than the lower. Thus the Ordovician beds outcropping at the bridge are not overturned, but upright, like the Johannian beds adjoining them, north of the fault.

On the opposite south shore of the harbour, sandstones and slates dip to the south and are probably of Johannian age. The assumption is made below that these beds are overturned. This cannot be verified at present, but overturning is not uncommon in the district. The problem is to restore the structure concealed beneath the waters of the harbour. While faulting may be a factor, the attempt is made to explain the structure by folding alone.

Fig. 1.

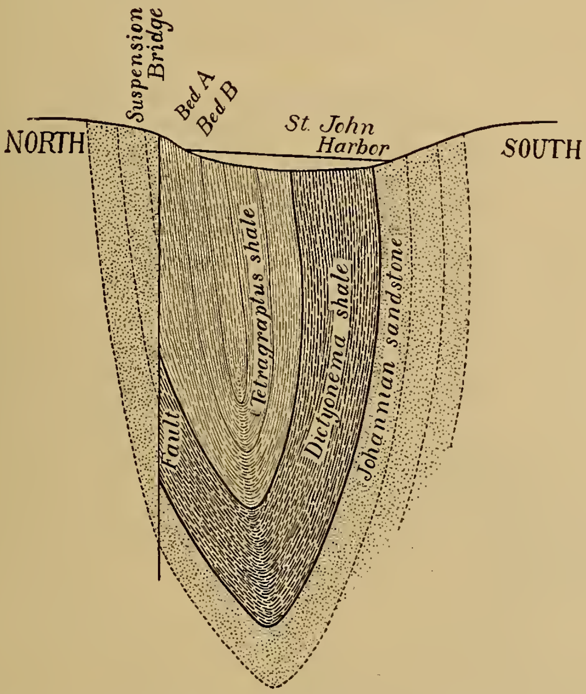

Fig. 1. A north-south section, Suspension Bridge, St. John, N. B.

The existence of a syncline may be inferred, for to the east, in the city of St. John, a section made by Matthew (1891, p. 126) shows that the rocks of the St. John Group are thrown into closed folds, with the black slates of the highest division, the Bretonian, lying in the synclines.

In order to define more closely the syncline of previous authors, the following hypothetical structure is here suggested. The Ordovician slates outcropping on the north shore, and which have been shown to be upright, lie in the northern limb of a syncline overturned to the south, whose axis lies beneath the waters of the harbour (see fig. 1). It follows from this interpretation that the slates in question are not the highest beds in the section but are overlain by higher strata in the center of the syncline beneath the harbour. The lower Dictyonema beds do not outcrop, because on the southern limb they are submerged and on the northern they are cut off by the fault.

The fauna.—Graptolites are abundant at two horizons, Bed A, 8 to 10 feet above the fault, and Bed B, from 20 to 25 feet higher. Between them, or 18 feet below the top, is an inch bed of badly crushed orthoids, more or less replaced by pyrite. The graptolites are often much distorted by deformation, making their identification difficult and sometimes uncertain. In the following table the collections from the two graptolite horizons are kept separate:

St. John, N. B., Suspension Bridge, Division 3*d* (Matthew)	Bed A	Bed B
Loganograptus logani Hall	r	
Tetragraptus quadribrachiatus (Hall)	r	
T. similis (Hall)?		r
Didymograptus extensus (Hall)	cc	cc
D. nitidus (Hall)	cc	c
D. patulus (Hall)	c	c
D. hirundo Salter ?	c	
D. simulans Elles and Wood	c	
D. v–fractus Salter	r	c
D. acutidens Lapworth, new var.		c
D. gracilis Törnquist		c
Phyllograptus ilicifolius Hall	r	
Protistograptus minutus (Matthew)	r	r
P. corrugatus (Matthew)	c	c

Eight of the above species are recorded for the first time from these beds, but Ami and Matthew (1892*b*) also record the following:

Graptolitoidea
- *Dictyonema delicatatum* Dawson var.
- *D. quadrangulare* Hall
- *Clonograptus flexilis* (Hall)
- *Didymograptus indentus* (Hall)
- *Retiograptus tentaculatus* Hall?

Brachiopoda
- *Orthis orthambonites* Pander
- *O.? euryone* Billings
- *O.* (*Dalmanella ?*) *electra* var. *major* Matthew
- *O. electra* var. *lævis* Matthew
- *O. menapiæ* var. *acadica* Matthew

Pteropoda
- *Styliola primæva* Matthew

Cephalopoda
- *Orthoceras* cf. *priamus* Billings
- *O.* cf. *catulus* Billings

Trilobita
- *Parabolinella posthuma* Matthew
- *Cyclognathus rotundifrons* Matthew
- *Euloma* sp.?

Stratigraphy and Correlation.—Matthew (1892*b*) and Ami described the fauna of the Tetragraptus zone in 1892 and correlated it with the Arenig of England. Later, Ruedemann (1904), on the basis of Matthew's publications, correlated it with the Tetragraptus zone (Beds 1 and 2) of the Deepkill, the main Point Lévis zone, and the Dichograptus zone of the Middle Skiddaw slates of the Lake District, England.

A considerable advance has been made in the study of graptolites since 1892. New species have been recognized and the successive zones have been worked out in greater detail. A reëxamination of the fauna, in the light of the new data, is therefore desirable in order to modernize the species and to fix the age as accurately as possible.

The fossils of horizon A are those of the Tetragraptus zone. *Didymograptus simulans*, which, according to Ruedemann, is not present in the Deepkill locality, links the fauna with that of the Middle Skiddaw slates of the Lake District. Elles (1898) subdivides this formation into (1) Upper Tetragraptus zone, (2) Dichograptus zone, and (3) Lower Tetragraptus zone. Local faunal lists are not given by Miss Elles, so that it is not easy to correlate accurately with these zones. Ruedemann, however, regards the Dichograptus zone as the equivalent of the Tetragraptus bed of the Deepkill. It is probable, therefore, that Bed A is to be compared with this zone in the Lake District.

Bed B contains an unusual assemblage of forms, linking it, on the one hand, with the Tetragraptus zone, and, on the other, with the *Didymograptus bifidus* zone. *Didymograptus v-fractus* has only been reported from the Lake District (Elles and Wood 1901) and is there confined to the Dichograptus bed of the Middle Skiddaw slates. Abundant *Didymograptus nitidus* and *D. extensus* are also more abundant in the Tetragraptus zone and its equivalents, although *D. extensus* may pass into the *D. bifidus* zone, as it does at Lévis, Quebec (Raymond). *D. gracilis* is common in and highly characteristic of the lower bed of the *D. bifidus* zone of the Deepkill (Ruedemann). It is rare in the Middle Skiddaw slates (horizon not indicated), and is also found in the Phyllograptus shales of Skattungbyn in Dalarne, Sweden (Ruedemann). *D. acutidens* is rare in the *D. bifidus* zone of the Deepkill, but present (Elles and Wood 1901) in the same horizon at St. Davids and in southern Shropshire in the Llanvirn (= Upper Arenig). Evans (1906) reports it from the *D. bifidus* bed of the Llanvirn of West Cærnarthenshire, Wales. The form present at St. John differs a little from Lapworth's species, but is a very close variety (*vide infra*).

Didymograptus v-fractus, common *D. nitidus* and *D. extensus*, and the absence of *D. bifidus* all indicate affinity with the Tetragraptus zone, and especially its equivalent in the Lake District, the Dichograptus zone of the Middle Skiddaw slates. *D. gracilis* links the fauna with that of the lower bed of the *D. bifidus* zone of the Deepkill. *D. acutidens* indicates affinity with the same horizon at St. David's, southern Shropshire, and western Cærmarthenshire.

Bed B, therefore, combines common Tetragraptus zone forms, including one confined to it, with two forms that usually occur in the next zone. It seems best, then, to regard the fauna of Bed B as a transitional one between those of the Tetragraptus and the *D. bifidus* beds.

A study of Raymond's lists (1914) of the Lévis, P. Q., zones shows that a similar early appearance of *D. bifidus* forms takes place there. Zone C_1 underlies the zone with *D. bifidus* and apparently holds the time of the Tetragraptus zone. In addition to a few common Tetragraptus zone forms and some local species, it contains a few kinds which in other localities occur at a higher horizon. Thus *Didymograptus similis* is highly characteristic of the *D. bifidus* zone of the Deepkill, and at the same horizon in northwestern Europe is represented by closely related or identical species, as Ruedemann has shown. *Ptilograptus geinitzianus* in the Deepkill occurs in the *D. bifidus* zone, although very rare. A species, *D.* cf. *indentus*, near to or identical with *Didymograptus indentus*, is also found at a higher horizon in Europe (Elles and Wood 1901).

It is evident that at St. John and Lévis some *D. bifidus* zone fossils occur at a lower horizon than in the Deepkill and European localities. At St. John, this may be explained by the existence of a transitional fauna. At Lévis, however, they occur in a zone which does not overlie a normal Tetragraptus fauna, and consequently there they may actually exist in Tetragraptus time and not, as at St. John, at a possibly somewhat later time.

The St. John graptolite fauna differs considerably from that at Lévis, only seven species being common to both, while nine or ten of the St. John species are not found at Lévis and about the same number of Lévis forms are absent at St. John. The faunal content of the St. John beds indicates a closer relation with northwestern Europe than with any American localities. The characteristically non-American species are *D. simulans*, *D. v-fractus*, *D. acutidens*, and *D. hirundo.*

Conclusions.—The study of the graptolite fauna under consideration shows that

(1) Two subhorizons are present, which, however, may be only of local importance.

(2) The lower subhorizon holds the time of the Tetragraptus zone, and the upper is transitional toward the *D. bifidus* zone.

(3) The faunas all show greater affinity with those of northwestern Europe, especially with the Lake District of England and St. Davids and Cærmarthenshire, Wales, than with Quebec or New York faunas.

(4) The succession shows that the Suspension Bridge slates are not overturned, but upright.

NOTES ON THE GRAPTOLITES.

Didymograptus acutidens Lapworth, new var.

The form present at St. John differs from Lapworth's species in having the proximal thecæ turned upward and only in contact for a small portion of their length. The distal thecæ have the normal characters of the species. This is probably a close variety of Lapworth's species.

Protistograptus, new genus.

Cyrtotheca Matthew (not Salter), Nat. Hist. Soc. New Brunswick, Bull. No. 10, 1892, p. viii.

Creseis Matthew (not Rang), Trans. Roy. Soc. Canada, vol. 10, sec. 4, 1892, p. 104.

An arched or straight cone, apex pointed, and the aperture terminating in a spine. The wall is carbonaceous, probably representing an original chitinous periderm. The cone is thought to be homologous with the sicula of all graptolites, and in smaller sizes is repeated in the ontogenetic development of all the species. The nema cannot be demonstrated in the specimens now available, although one or two individuals of *Protistograptus corrugatus* show what may be the beginning of such a process (see fig. 2*e*). The size varies, but a maximum length of 10^{mm} and a maximum breadth of $1{\cdot}2^{mm}$ may be attained.

Remarks.—The genus is probably to be regarded as the prototype of the Graptolitoidea, just as *Paterina* occupies a similar place in the Brachiopoda. The analogy is not an exact one, however, because the sicular cone includes more than the embryonic shell, i. e., more than the equivalent of the prodissoconch of the Pelecypoda, the protaspis of the Trilobita, or the protegulum of the Brachiopoda. On the basis of the morphological studies of Wiman, Holm (1895, p. 3) considers the initial part of the sicula with the thin periderm to be the embryonic shell, and the apertural part with growth lines, apertural spine, etc., to be a later growth. Ruedemann, by comparison with the development of a tubularian hydroid, demonstrates that the initial part of the sicula, the nema, and the disc, all together make up the embryonic shell. In *Protistograptus*, the presence of a post-embryonic structure, the apertural spine, shows that the genus is the homologue of a sicula, i. e., of the embryonic shell plus some later growth. It is still, however, in the single zoöid stage.

By budding and dichotomy, the rhabdosome would pass through *Didymograptus*, *Tetragraptus*, etc., stages. This statement does not necessarily mean that the genera referred to arose in this order, but that the graptolites, at some time in their history, probably passed through similar stages.

The detailed characters in the various siculæ have not, as yet, been demonstrated to be of value in phylogenesis. Thus each phylum may be characterized by a particular kind of sicula, or the sicula itself may take on new characters *pari passu* with the evolution of the rhabdosome. The sicula is seldom described in detail, so that it is impossible to determine whether its variations in form and structure are of genetic value. It is equally impossible to determine what are the primitive characters of a sicula, but the literature and figures show that they vary in slenderness, shape, and number and shape of the spines.

It may be inferred that the most primitive sicula would be straight, conical, and without apertural processes, i. e., a mere continuation of the embryonic shell. The sicula of *Corynoides* fulfills these requirements most closely. Here the sicula is a short or long cone without an apertural spine. This genus possesses other characters that may be interpreted as primitive—

the fewness of thecæ and the absence of dichotomy. Here apparently a primitive sicula accompanies a primitive genus. On the other hand, the apertures of some of the Diplograptidæ are more complex, with lobes and spines.

The species of *Protistograptus* described below depart from the primitive type of a sicula in their curvature and apertural spine or lobe. These characters exclude them from direct genetic relationship with *Corynoides*, although that is the nearest known genus in fewness of thecæ. *P. corrugatus* approaches in size the siculæ of *Goniograptus perflexilis* and *G. geometricus*, but it is larger and different in form. The siculæ of *Goniograptus* are straight, while those of the known species of *Protistograptus* are wholly, or in part, curved.

While *Protistograptus* is structurally ancestral to all graptolites and is found associated with the second graptolite fauna (*Dictyonema flabelliforme* preceding), it seems probable that the known species depart from the primitive type and are not directly genetically related to any of the known graptolite phyla.

Protistograptus minutus (Matthew).

Cyrtotheca minuta Matthew, Nat. Hist. Soc. New Brunswick, Bull. No. 10, 1892, p. viii.

Creseis minuta Matthew, Trans. Roy. Soc. Canada, vol. 10, sec. 4, 1892, p. 105, pl. 7, figs. 11*a*–11*c*.

"A minute elongated arched cone or sheath, acutely pointed at the apex, near which the shell is more rigid than at the larger end. . . . The outer surface is smooth, except toward the apex where some examples show longitudinal ridges. Under the microscope the surface is seen to be minutely striulate transversely. . . . Length 4^{mm}. Width about one-fifth of the length."

The species may be further described as an arched, rapidly expanding cone. Apertural margin rises in an acute spine.

A large specimen (see fig. 2*a*) is 7^{mm} long, broadly arched, and rapidly expands to an apertural width of $1{\cdot}2^{mm}$. Apertural margin inclined on the concave side at an angle of 120° and on the convex side rises more steeply, forming an acute spine. Carbonaceous layer almost wholly removed. Surface with numerous transverse cracks which are not filled with carbonaceous matter and are too irregular for transverse diaphragms. Matthew, in his specimens, finds ridges which are "often very regularly spaced and may possibly mark the position of diaphragms." The writer's specimens do not show these.

A few small specimens (see fig. 2*b*) also exhibit the characteristic rapid widening of the sheath, but the aperture is obscure. One of these shows longitudinal ridges, which, however, are due to crushing in the sediment.

This species is rare in the Yale collection and occurs chiefly in the lower horizon (A).

Protistograptus corrugatus (Matthew).

Cyrtotheca corrugata Matthew, Nat. Hist. Soc. New Brunswick, Bull. No. 10, 1892, p. viii.

Creseis corrugata Matthew, Trans. Roy. Soc. Canada, vol. 10, sec. 4, 1892, p. 105, pl. 7, figs. 12a–12b.

"A sheath more elongated than the preceding [*P. minutus*]; it is also larger, straighter, and is traversed by numerous, closely set undulations of the surface, forming rings that fade out toward the larger end of the shell. Length 10 mm., width about one tenth of the length."

Fig. 2.

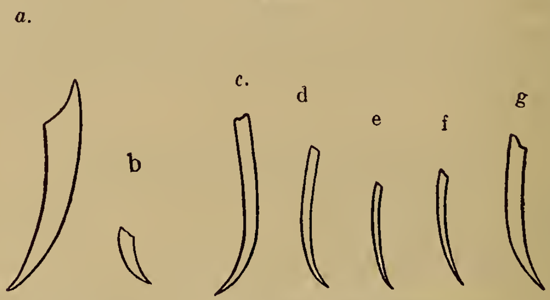

Fig. 2 *a*, *b*. *Protistograptus minutus* (Matthew).

a. Large specimen showing aperture.
b. Younger form.

Fig. 2 *c–g*. *Protistograptus corrugatus* (Matthew).

c-d. Form with straight apertural region.
e-f. More attenuated variety.
g. Shows character of aperture.

Study of the Yale specimens emphasizes the following specific characters: An elongated cone, expanding gradually, arched in the apical portion and almost straight and cylindrical in the apertural portion. A variation occurs in which the whole cone is arched and the apical end extremely attenuated. In one or two specimens this extends into what seems to be a short nema. None of the specimens show the "undulations" described by Matthew.

A large specimen (fig. 2*c*) is 6 mm. long and 0·4 mm. in width at the aperture, curved in the apical part and straight in the distal portion. Another specimen (fig. 2*d*) shows a longer curved part. Figures 2*e* and 2*f* illustrate a common variation, in which the whole cone is broadly curved. They are elongated and extremely attenuated at the apex. One specimen (fig. 2*e*) is extended into an apparent stout nema.

Another variation, nearer the type, is that shown in figure 2*g*, which illustrates a specimen somewhat broader and not quite straight in the apertural part. The aperture is preserved and is quite different from that of *P. minutus.* One third of the apertural margin is normal to the concave side of the cone. The remaining portion of the apertural margin rises at an angle of 50°, is somewhat rounded, and forms an obtuse spine or lobe.

This species is the most abundant in the Yale collection in both A and B beds, although Matthew found it not so abundant as *P. minutus.*

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Art. V.—*A Study of the Recent Crinoids which are Congeneric with Fossil Species;** by Austin H. Clark.

In attempting to interpret past conditions by an intensive study of the present, one of the most natural methods is a direct comparison between congeneric fossil and recent forms.

Unfortunately this method is beset with difficulties, for recent types with abundant fossil congeneric representation are usually rare and local, or occupy very specialized and circumscribed habitats, while abundant and widely spread recent types usually are represented by a very few rare and local close fossil relatives.

The great preponderance of the fossil over the recent stalked crinoids has given rise to the idea that in this group more than in others such a study might be of value; but when we examine the situation in detail we see that the recent crinoids in this respect are scarcely more promising than many other types of marine organisms.

In the present seas there exist 21 genera of stalked crinoids, which are distributed among 6 families (Pentacrinitida, Apiocrinidæ, Phrynocrinidæ, Bourgueticrinidæ, Holopodidæ and Plicatocrinidæ), falling in two orders (Articulata and Inadunata, the latter including the Plicatocrinidæ only). Of these 21 genera only 5 (if we consider *Proisocrinus* and *Carpenterocrinus* together as the recent equivalent of *Millericrinus*) possess fossil species, while one of the families (Phrynocrinidæ), including 2 genera, is recent only.

The recent genera of stalked crinoids, together with the fossil genera in the families to which they belong, are given in the following list:

Order Articulata

Pentacrinitida

Recent	Fossil
Isocrinus	Isocrinus
Metacrinus	*Pentacrinus*
Hypalocrinus	*Balanocrinus*
Teliocrinus (*Comastrocrinus*)	*Austinocrinus*
Endoxocrinus	

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Apiocrinidæ

Recent	Fossil
PROISOCRINUS CARPENTEROCRINUS	MILLERICRINUS
	Apiocrinus
	Guettardocrinus
	Dadocrinus
	Holocrinus
	Achrochordocrinus

Phrynocrinidæ

Recent	Fossil
Phrynocrinus *Naumachocrinus*	None

Bourgueticrinidæ

Recent	Fossil
RHIZOCRINUS	RHIZOCRINUS
DEMOCRINUS	(*DEMOCRINUS)
Bythocrinus	*Bourgueticrinus*
Monachocrinus	*Mesocrinus*
Bathycrinus	*Dolichocrinus*
Ilycrinus	

Holopodidæ

Recent	Fossil
HOLOPUS	HOLOPUS
	Cotyloderma
	Cyathidium

Order INADUNATA.

Plicatocrinidæ

Recent	Fossil
Calamocrinus	*Plicatocrinus*
Ptilocrinus	
Hyocrinus	
Gephyrocrinus	
Thalassocrinus	

In the preceding list the genus *Democrinus*, a widely spread recent type, is included also among the fossil forms. The first species of this genus known was found in a recent breccia in the West Indian island of Guadeloupe; as the breccia also contained a human skeleton, its age could not have been very great.

If we compare the recent and fossil generic types in each of the families given above, we at once notice, especially in the two families in which recent and fossil genera are about equally numerous (Pentacrinitida and Bourgueticrinidæ) that the two groups diverge in more or less different directions, for each has developed along somewhat different lines from the other. It is evident, therefore, that an ecological comparison between recent and fossil forms is unsatisfactory unless based upon strictly congeneric species.

In the recent seas the stalked crinoids have been very largely supplanted by a curious unstalked type, the comatulid, which is most extraordinarily developed, though systematically it forms only one (Comatulida) of the three sections (Comatulida, Thiolliericrinida and Pentacrinitida) of the family Pentacrinitidæ. Of the comatulids, represented in the recent seas by 100 genera included in 21 families, only 2 genera, both belonging to the same family, are both fossil and recent.

Considering all the recent crinoids together, we find that of the 121 genera and 27 families occurring in the present seas, 7 genera representing 5 families and including 20 recent species are known also as fossils. In addition to these there is the genus *Democrinus*, including 4 species, the status of which was explained above.

In the following table are given all of the recent crinoid genera which include fossil species, with the data for each.

The recent species of *Eudiocrinus* are:

Eudiocrinus indivisus (Semper)
Eudiocrinus junceus A. H. Clark
Eudiocrinus minor A. H. Clark
Eudiocrinus ornatus A. H. Clark
Eudiocrinus pinnatus A. H. Clark
Eudiocrinus serripinna A. H. Clark
Eudiocrinus variegatus A. H. Clark
Eudiocrinus venustulus A. H. Clark

The recent species of *Catoptometra* are:

Catoptometra hartlaubi (A. H. Clark)
Catoptometra magnifica A. H. Clark
Catoptometra ophiura A. H. Clark
Catoptometra rubroflava (A. H. Clark)

The recent species of *Isocrinus* are:

Isocrinus asterius (Linné)
Isocrinus blakei (P. H. Carpenter)
Isocrinus decorus (Wyville Thomson)

The recent species referable to *Millericrinus* are:

Carpenterocrinus mollis (P. H. Carpenter)
Proisocrinus ruberrimus A. H. Clark

The recent species of *Democrinus* are:

Democrinus parfaiti Perrier
Democrinus rawsonii Pourtalès
Democrinus sabæ (A. H. Clark)
Democrinus weberi (Döderlein)

The recent species of *Rhizocrinus* are:

Rhizocrinus lofotensis M. Sars
Rhizocrinus verrilli A. H. Clark

	Recent Species	Fossil Species	Horizon	Locality	Recent Distribution	Bathymetric Range	Thermal Range
Zygometridæ *Eudiocrinus*	8	1	Jurassic	Switzerland	Malay Archipelago to Japan	22–62 fathoms	No Records
Catoptometra	4	Many	Jurassic; Tertiary	Europe; North Africa; Patagonia	Philippine Islands and Hong Kong, and northward to Japan	14–153 fathoms	56·0–62·1 F.
Pentacrinitida *Isocrinus*	3	Many	Trias; Jurassic	North America; Europe; Australia	Caribbean Sea and Gulf of Mexico	5–667 fathoms	49·5–69·0 F.
Apiocrinidæ *Millericrinus* (*Proisocrinus*) (*Carpenterocrinus*)	 1 1	Many	Lias; Lower Cretaceous	Europe	Celebes to southern Japan	565–940 fathoms	36·7–38·1 F.
Bourgueticrinidæ (*Democrinus*)	4	1	Recent Breccia	West Indies	East Indies; Morocco; Caribbean Sea and Gulf of Mexico	62–1139 fathoms	No Records
Rhizocrinus	2	3	Cretaceous; Eocene	New Jersey; Alabama; Europe	Florida to Newfoundland and Iceland, and eastward to Ireland and Norway	77–1300 fathoms	32·2–48·7 F.
Holopodidæ *Holopus*	1	1	Tertiary	Italy	West Indies	5–120 fathoms	71·0 F. (One Record)

The recent species of *Holopus* is:

Holopus rangii d'Orbigny

The frequency according to depth of the recent representatives of these genera is as follows:

0– 50	4	550– 600	4
50–100	6	600– 650	4
100–150	5	650– 700	4
150–200	4	700– 750	3
200–250	3	750– 800	3
250–300	3	800– 850	3
300–350	3	850– 900	3
350–400	3	900– 950	3
400–450	3	950–1000	2
450–500	3	1000–1100	2
500–550	3	1100–1200	2
1200–1300	1		

The frequency according to temperature of the recent representatives of these genera is as follows:

70°–72°	1	50°–52°	1
68 –70	1	48 –50	2
66 –68	1	46 –48	1
64 –66	1	44 –46	1
62 –64	2	42 –44	1
60 –62	2	40 –42	1
58 –60	2	38 –40	2
56 –58	2	36 –38	2
54 –56	1	34 –36	1
52 –54	1	32 –34	1

In the following table is given a comparison between these genera and the genera confined to the Indo-Pacific, confined to the Atlantic, and common to both oceans.

The most noticeable fact in regard to the recent genera with fossil species is their very restricted geographical distribution; aside from *Democrinus* none of them occur in more than one ocean basin, and, moreover, they occupy collectively only a very small portion of the present seas.

They are entirely confined to two small areas, (1) in the west Pacific from the Malay Archipelago to southern Japan, and (2) in the west Atlantic from the West Indies to Iceland, Ireland and Norway.

This distribution is particularly interesting when compared with the almost identical distribution of the Xiphosuridæ (Horseshoe Crabs), *Lingula*, and other ancient types.

	Total Range	Average Range	Mean Depth of Habitat	Total Thermal Range	Mean Thermal Range	Mean Temperature of Habitat
Recent Species belonging to fossil Genera	1295	425	327	38°·8	11°·0	53°·4
Plus Democrinus	1295	519	366	----	----	----
Exclusively Indo-Pacific Genera	2575	244	264	----	----	----
Exclusively Atlantic Genera	1300	401	291	----	----	----
Genera common to both Oceans	2900	1057	785	----	----	----

According to their geographical distribution these genera group themselves as follows:

Confined to the western Pacific:

Eudiocrinus
Catoptometra (Fossil in Patagonia)
Proisocrinus
Carpenterocrinus

Confined to the western or western and northern Atlantic, but occurring as fossils in the Indo-Pacific basin:

Isocrinus
Rhizocrinus
Holopus

Common to the Indo-Pacific and Atlantic:

Democrinus

It is interesting to note that all but one of these genera is chiefly developed in shallow water; this single exception is also the only one which, so far as we know, does not occur within 100 fathoms of the surface, three of the others being entirely confined to water of less than 155 fathoms in depth.

In the total range, average range, and mean depth of habitat these genera show a close approximation to the genera peculiar to the Atlantic, in contrast to those peculiar to the Indo-Pacific, which have much greater total range, but lesser average range and mean depth of habitat, and to those common to both oceans, which have a much greater average range and mean depth of habitat, as well as total range.

In depth the maximum representation is between 0 and 200 fathoms, especially between 50 and 150 fathoms. As, taking the ocean as a whole, we find at a depth of 200 fathoms a temperature of 50°·1, and at 100 fathoms 60°·7, it is evident that these genera are most strongly represented within the optimum temperature for crinoid life, which is between 50° and 65°.

Temperature records are, unfortunately, few, and the table showing the frequency of the genera at different temperatures is, therefore, of uncertain value. But it is interesting to observe that, excepting *Proisocrinus* and *Carpenterocrinus* which are only known from a single dredge haul each, between the temperatures 36° and 40°, the only increase in the numbers falls between 50° and 64°, that is, within the optimum temperature for crinoids, and is particularly emphasized between 56° and 64°, the emphasis within the optimum temperature range being between 60° and 65°.

Art. VI.—*The Relation between the Maximum and the Average Bathymetric Range, and the Mean and the Average Depth of Habitat, in the Subfamilies and Higher Groups of Recent Crinoids*;[*] by Austin H. Clark.

In the discussion of the bathymetric distribution of the various classes of marine invertebrates relatively little attention has heretofore been paid to the question of the average as compared with the total bathymetric range, and to the average as compared with the mean depth of habitat. Yet this aspect of the study of bathymetric distribution is of the greatest importance on account of its possible bearing on problems connected with paleontology.

The maximum and the average bathymetric ranges, and the mean and the average depth of habitat, of the subfamilies and higher groups of recent crinoids are given in the following table:

The Maximum and the Average Bathymetric Range, and the Mean and the Average Depth of Habitat, of the Subfamilies and Higher Groups of Recent Crinoids. The three families marked with an asterisk (*) are monotypic.

	Maximum Range	Average Range	Mean depth of habitat	Average depth of habitat
ARTICULATA	2900	412	1450	595
PENTACRINITIDÆ	2900	529	1450	408
Comatulida	2900	429	1450	390
Oligophreata	1600	167	800	118
Comasteridæ	830	153	415	96
Capillasterinæ	830	189	415	154
Comactiniinæ	288	180	144	90
Comasterinæ	140	90	70	45
Zygometridæ	153	76	76	50
Himerometridæ	61	33	30	22
*Stephanometridæ	35	35	17	17
Mariametridæ	84	45	42	26
Colobometridæ	140	45	70	32
*Tropiometridæ	278	278	139	139
Calometridæ	333	142	166	102
Thalassometridæ	1600	402	800	274
Ptilometrinæ	134	54	73	53
Thalassometrinæ	1600	507	800	340
Charitometridæ	1170	464	615	423
Macrophreata	2900	691	1450	663
Antedonidæ	2900	572	1450	409
Antedoninæ	250	146	125	76

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[*] Published with the permission of the Secretary of the Smithsonian Institution.

	Maximum Range	Average Range	Mean depth of habitat	Average depth of habitat
Thysanometrinæ	549	338	298	216
Zenometrinæ	1588	383	809	315
Perometrinæ	209	133	138	114
Heliometrinæ	1600	633	800	383
Bathymetrinæ	2820	1801	1490	1349
Pentametrocrinidæ	1679	1193	951	828
Atelecrinidæ	616	308	599	753
Pentacrinitida	1345	629	678	427
APIOCRINIDÆ	375	0	753	753
PHRYNOCRINIDÆ	44+	0	620	620
BOURGUETICRINIDÆ	2628	1415	1376	1134
*HOLOPODIDÆ	115	115	62	62
INADUNATA	2309	952	1420	1378
PLICATOCRINIDÆ	2309	952	1420	1378

The range in depth covered by the families of crinoids inhabiting the recent seas varies from 35 fathoms in the Stephanometridæ to a maximum of 2820 fathoms in the Bathymetrinæ. The sequence of the families according to the bathymetric range is as follows:

Stephanometridæ	35	fathoms	Calometridæ	333	fathoms
Phrynocrinidæ	44+	"	Apiocrinidæ	375	"
Himerometridæ	61	"	Thysanometrinæ	549	"
Mariametridæ	84	"	Atelecrinidæ	616	"
Holopodidæ	115	"	Capillasterinæ	830	"
Ptilometrinæ	134	"	Charitometridæ	1170	"
Comasterinæ	140	"	Zenometrinæ	1588	"
Colobometridæ	140	"	Thalassometrinæ	1600	"
Zygometridæ	153	"	Heliometrinæ	1600	"
Perometrinæ	209	"	Pentametrocrinidæ	1679	"
Antedoninæ	250	"	Plicatocrinidæ	2309	"
Tropiometridæ	278	"	Bourgueticrinidæ	2628	"
Comactiniinæ	288	"	Bathymetrinæ	2820	"

Average range in depth for all families 732 fathoms

The several contrasting groups give the following figures:

More specialized			Less specialized		
Articulata	2900	fathoms	Inadunata	2309	fathoms
Pentacrinitidæ	2900	"	Bourgueticrinidæ	2628	"
Comatulida	2900	"	Pentacrinitida	1345	"
Oligophreata	1600	"	Macrophreata	2900	"

The stalked groups, arranged according to their phylogenetic position, have bathymetric ranges as follows:

Pentacrinitidæ	2900	fathoms
Pentacrinitida	1345	"
Apiocrinidæ	375	"
Phrynocrinidæ	44 +	"
Bourgueticrinidæ	2628	"
Holopodidæ	115	"
Plicatocrinidæ	2309	"

It is evident that, while as a rule the more specialized families possess small, and the less specialized large, bathymetric ranges, there is no hard and fast line between the two groups; for we find the Jurassic Zygometridæ with a range of only 153 fathoms, while the apparently very modern Bathymetrinæ has the greatest range of all, 2820 fathoms (fig. 1, lower border of the black areas).

So far as we know, pressure has no influence whatever upon the distribution of the crinoids, which is determined primarily by temperature; thus the actual bathymetric range of any crinoid species, genus or higher group means nothing unless we know how large a temperature range it covers.

For instance, the family Plicatocrinidæ covers a range of 2309 fathoms, but the maximum variation in temperature which it is known to withstand is 12·8° Fahrenheit, while the subfamily Comasterinæ has a bathymetric range of only 140 fathoms, but a thermal range of 27·7° Fahrenheit.

The more specialized families possess small bathymetric ranges solely for the reason that they occur in the littoral zone where the isotherms are most numerous and most closely crowded.

For comparison with the table of contrasting groups given above the following table, giving the temperature range of each, is given:

More specialized		Less specialized	
Articulata	51·3° Fahr.	Inadunata	12·8° Fahr.
Pentacrinitidæ	50·4	Bourgueticrinidæ	41·6
Comatulida	50·4	Pentacrinitida	35·0
Oligophreata	45·8	Macrophreata	50·4

From this table it would appear that the thermal range (or in other words the thermal adaptability) of the crinoid groups increases with specialization.

According to their average bathymetric ranges, that is, their bathymetric ranges calculated as the average of the bathymetric ranges of all the included genera, the crinoid families including recent representatives arrange themselves as follows:

Fig. 1.

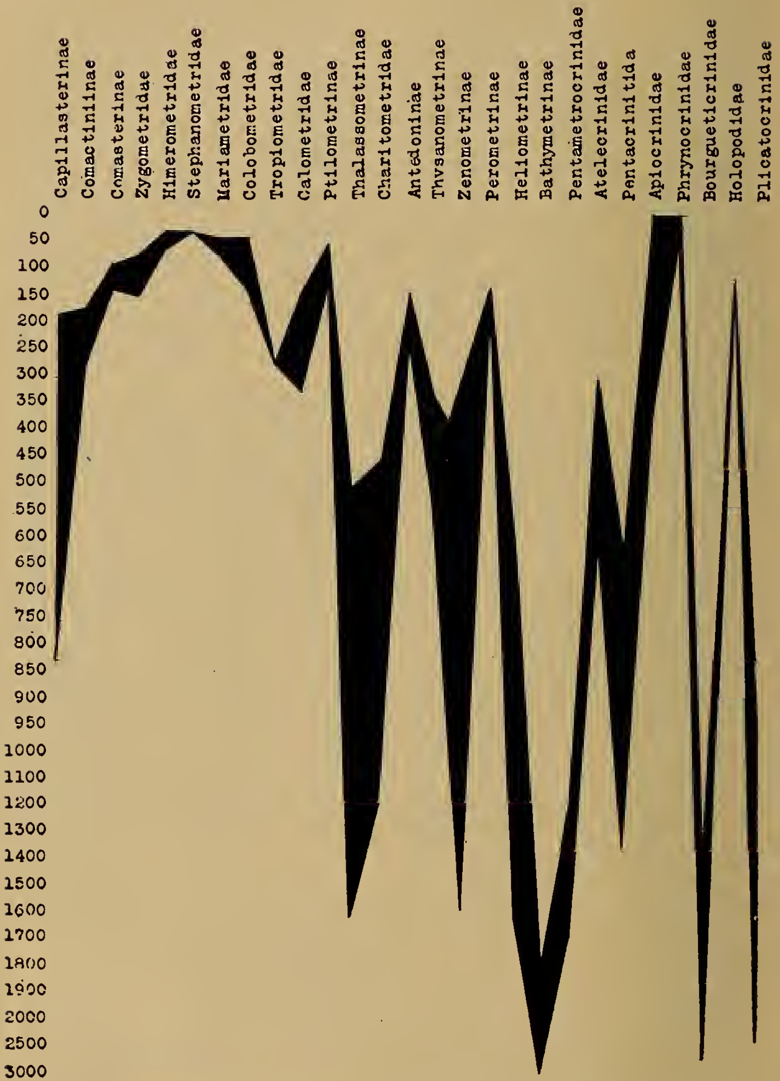

Fig. 1. The Difference between the Maximum and the Average Bathymetric Range of the Families of Recent Crinoids.

Himerometridæ	33	fathoms	Capillasterinæ	189	fathoms
Colobometridæ	45	"	Atelecrinidæ	308	"
Mariametridæ	45	"	Thysanometrinæ	338	"
Ptilometrinæ	54	"	Zenometrinæ	383	"
Zygometridæ	76	"	Charitometridæ	464	"
Comasterinæ	90	"	Thalassometrinæ	507	"
Perometrinæ	133	"	Heliometrinæ	633	"
Calometridæ	142	"	Plicatocrinidæ	952	"
Antedoninæ	146	"	Pentametrocrinidæ	1193	"
Comasterinæ	180	"	Bourgueticrinidæ	1415	"

Bathymetrinæ 1801 fathoms

Average for all the families 435 fathoms

In the preceding table the families Stephanometridæ, Tropiometridæ and Holopodidæ, monotypic, and Apiocrinidæ, and Phrynocrinidæ, insufficiently known, are omitted.

The average ranges of the contrasting groups are as follows:

More specialized			Less specialized		
Articulata	412	fathoms	Inadunata	952	fathoms
Pentacrinitidæ	529	"	Bourgueticrinidæ	1415	"
Comatulida	429	"	Pentacrinitida	629	"
Oligophreata	167	"	Macrophreata	691	"

and of the stalked groups:

Pentacrinitidæ	529	fathoms
Pentacrinitida	629	"
Bourgueticrinidæ	1415	"
Holopodidæ	115	"
Plicatocrinidæ	952	"

The average bathymetric range of the families of crinoids existing in the recent seas varies between 33 fathoms in the Himerometridæ and 1801 fathoms in the Bathymetrinæ (fig. 1, upper border of the black areas). In examining the list of contrasted groups it is clearly evident that the more specialized the group the less becomes its average bathymetric range. The same thing is indicated in the list of the stalked types, if we bear in mind that the family Holopodidæ is restricted to the Caribbean Sea and therefore does not come into competition with the more widely spread forms, and that the genera of the Plicatocrinidæ are not sufficiently known to enable us to make any definite statements in regard to it.

In the following list the families of crinoids which include living species are given, arranged according to the average depth of habitat (fig. 2, upper border of the black areas):

Fig. 2

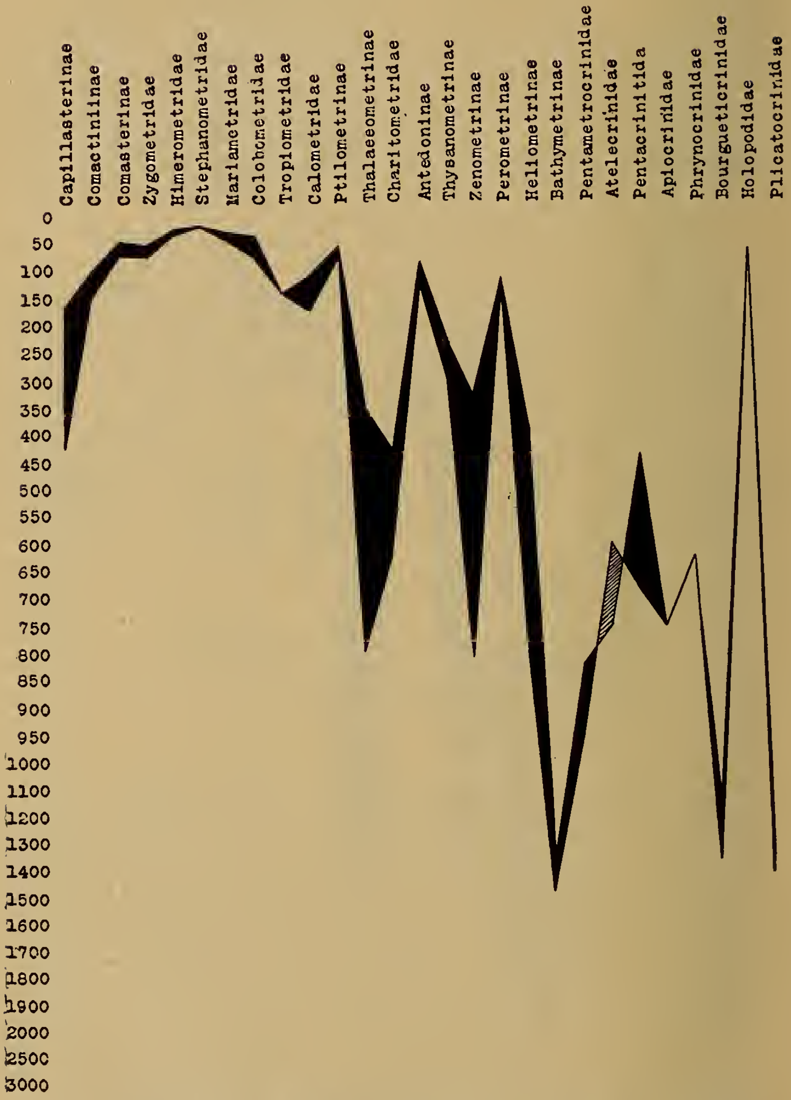

Fig. 2. The Difference between the Mean and the Average Depth inhabited by the Families of Recent Crinoids.

Stephanometridæ	17	fathoms	Capillasterinæ	154	fathoms
Himerometridæ	22	"	Thysanometrinæ	216	"
Mariametridæ	26	"	Zenometrinæ	315	"
Colobometridæ	32	"	Thalassometrinæ	340	"
Comasterinæ	45	"	Heliometrinæ	383	"
Zygometridæ	50	"	Charitometridæ	423	"
Ptilometrinæ	53	"	Phrynocrinidæ	620	"
Holopodidæ	62	"	Atelecrinidæ	753	"
Antedoninæ	76	"	Apiocrinidæ	753	"
Comactiniinæ	90	"	Pentametrocrinidæ	828	"
Calometridæ	102	"	Bourgueticrinidæ	1134	"
Perometrinæ	114	"	Bathymetrinæ	1349	"
Tropiometrinæ	139	"	Plicatocrinidæ	1378	"

Average 364 fathoms

The average depth of habitat of the contrasted groups is:

Articulata	595	fathoms	Inadunata	1378	fathoms
Pentacrinitidæ	408	"	Bourgueticrinidæ	1134	"
Comatulida	390	"	Pentacrinitida	427	"
Oligophreata	118	"	Macrophreata	663	"

and of the stalked groups:

Pentacrinitidæ	408	fathoms
Pentacrinitida	427	"
Apiocrinidæ	753	"
Phrynocrinidæ	620	"
Bourgueticrinidæ	1134	"
Holopodidæ	62	"
Plicatocrinidæ	1378	"

Considering the list of contrasted groups it is evident that the more specialized the group the less the average depth at which it is found. The same thing is shown by the list of stalked groups, if we bear in mind that *Holopus* is a very restricted and aberrant type, and that our knowledge of the Apiocrinidæ and of the Phrynocrinidæ is very limited.

It is interesting to observe that the average range of the families of recent crinoids is very nearly the same as, but slightly more than, the average depth of habitat. The correspondence of the two is strikingly brought out in the accompanying diagram (fig. 3).

FIG. 3.

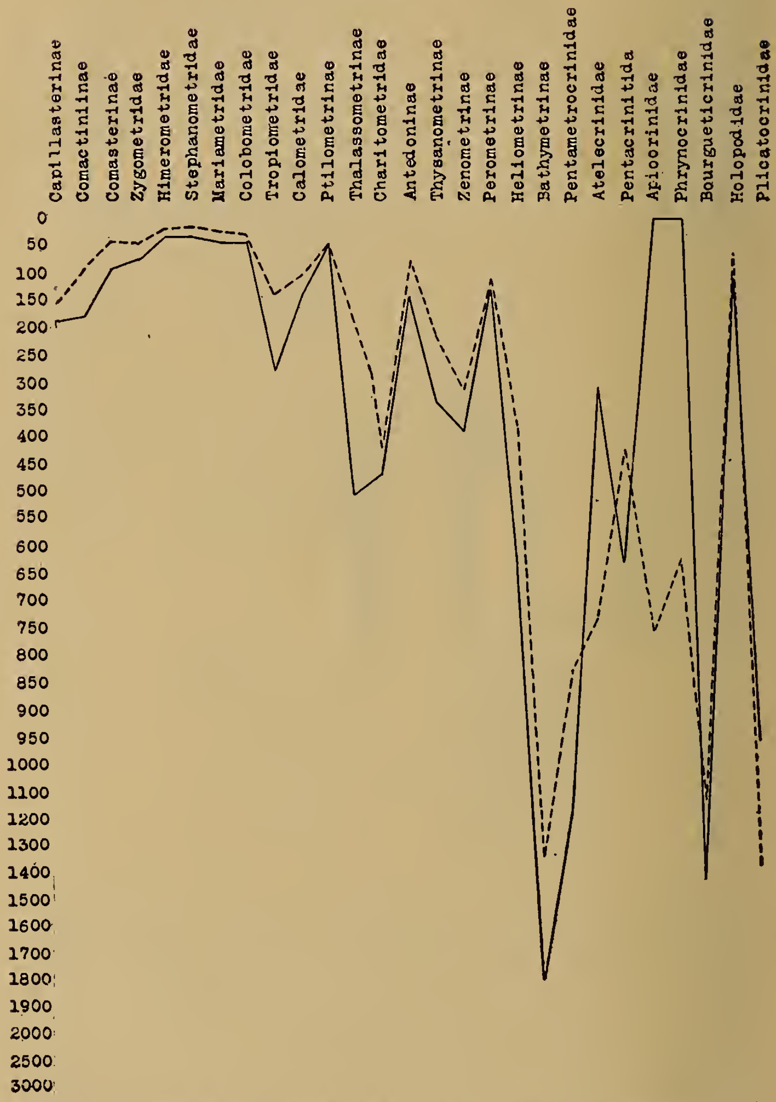

FIG. 3. Comparison of the Average Range (——) and the Average Depth of Habitat (——) of the Families of Recent Crinoids.

Art. VII.—*The Separation of Potassium and Sodium by the Use of Aniline Perchlorate, and the Subsequent Estimation of the Sodium;* by D. U. Hill.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—cclxviii.]

The chief purpose of the experiments to be described was to determine the availability, as a method for estimating sodium quantitatively, of the precipitation of sodium chloride from solution in alcohol by means of gaseous hydrogen chloride, after the removal of potassium as perchlorate. Kreider and Breckenridge* have determined the delicacy of the qualitative test for sodium made in this way, and have found that "even in 40$^{cm^3}$ 0·0002 grm. of sodium oxide can be seen distinctly; from which fact," they conclude, "it is evident that this method can be applied to the quantitative determination of sodium."

The possibility of substituting aniline perchlorate for perchloric acid as precipitant of the potassium has, also, been tested in the present investigation. Aniline perchlorate forms crystals of definite composition, without water of crystallization, so that the amount to be used can be readily determined by weighing. A greater advantage which it was thought the use of the aniline salt would have over the acid, viz., that it could be more easily prepared, proved to be illusory. Aniline expels the ammonia from ammonium perchlorate when the two substances are boiled together, but the reaction is slow and during the boiling the aniline develops a dark color. No convenient way of getting rid of this color could be found. Other methods for preparing aniline perchlorate, starting with the ammonium salt, suggest themselves, as, for instance, the conversion of ammonium perchlorate into barium percholate by boiling with barium hydroxide, and then into aniline perchlorate by dissolving in dilute alcohol, adding aniline, precipitating the barium as chloride by hydrochloric gas and ether, and evaporating off the excess of hydrochloric acid; or by mixing exactly equivalent amounts of barium perchlorate and aniline sulphate.† But all of these methods are more laborious than the preparation of perchloric acid by Willard's‡ method, i. e., the oxidation of ammonium perchlorate to perchloric acid by dilute aqua regia. Indeed, the easiest way to prepare the aniline perchlorate is to make the acid first by this very simple method, and then to add aniline to a water solution of the acid until some of the oil remains after shaking, and boil vigor-

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* This Journal (4), ii, 263–8, 1896.

† Spallino, Ann. Chim. applicata, i, 435; Chem. Abs. viii, 2701, 1914.

‡ Jour. Am. Chem. Soc., xxxiv, 1480–5, 1912.

ously to expel the excess aniline with the steam before it has time to darken. Colorless crystals are obtained in this way.

Experiments were made first to determine the completeness of the precipitation of sodium chloride from 97 per cent alcohol by gaseous hydrogen chloride. The method was as follows: 0·1000 grm. of purified sodium chloride was dissolved in $1{\cdot}5^{cm^3}$ of water, $48{\cdot}5^{cm^3}$ of absolute alcohol was added (this amount of 97 per cent alcohol will not hold much more than 0·05 grm. of sodium chloride in solution), and gaseous hydrogen chloride (conveniently evolved by the action of concentrated sulphuric acid upon massive ammonium chloride in a Kipp generator) was passed into the cooled solution through an inverted funnel. When the solution appeared to be saturated with the gas, the precipitate was collected on asbestos in a perforated crucible, dried at about 110°, and weighed. Table I shows the results of these experiments:

TABLE I.

	NaCl taken grm.	NaCl found grm.	Error on NaCl grm.	Error on Na_2O grm.
(1)	0·1000	0·0994	—0·0006	—0·0003
(2)	0·1000	0·0989	—0·0011	—0·0006
(3)	0·1000	0·0994	—0·0006	—0·0003
(4)	0·1000	0·0992	—0·0008	—0·0004

A series of experiments was then made in which both potassium and sodium were estimated. Equal amounts of recrystallized potassium chloride and sodium chloride were weighed out and dissolved in $1{\cdot}5^{cm^3}$ of water. The amounts used are shown in Table II. An excess of aniline perchlorate (about ·5 grm.) dissolved in $48{\cdot}5^{cm^3}$ of absolute alcohol was then added, and the precipitate of potassium perchlorate was filtered off on a perforated crucible with the aid of suction, and washed with about 20^{cm^3} of 97 per cent alcohol. The precipitate was dried at 110° and weighed. The filtrate was saturated with hydrogen chloride from the Kipp generator as in the previous experiments, the precipitate of sodium chloride collected on a perforated crucible, washed with a saturated solution of hydrogen chloride in 97 per cent alcohol, dried and weighed. The results of this series of experiments are shown in Table II.

The errors on potassium are greater than those obtained by Kreider,* who took pains to convert the potassium chloride completely into perchlorate by evaporating it twice with perchloric acid to a syrup-like consistency, and in washing used 97 per cent alcohol containing perchloric acid, finishing with a very little pure alcohol. In the case of sodium the experi-

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* This Journal (3), xlix, 443–8, 1895.

TABLE II.

	KCl taken grm.	$KClO_4$ found grm.	Error on K_2O grm.	NaCl taken grm.	NaCl found grm.	Error on Na_2O grm.
(1)	0·0500	0·0932	+0·0001	0·0500	0·0496	−0·0002
(2)	0·0400	0·0729	−0·0005	0·0400	0·0392	−0·0004
(3)	0·0400	0·0727	−0·0006	0·0400	0·0393	−0·0004
(4)	0·0400	0·0728	−0·0006	0·0400	0·0394	−0·0003
(5)	0·0300	0·0558	0·0000	0·0300	0·0293	−0·0004
(6)	0·0300	0·0556	−0·0001	0·0300	0·0295	−0·0003
(7)	0·0300	0·0543	−0·0005	0·0300	0·0295	−0·0003
(8)	0·0300	0·0540	−0·0006	0·0300	0·0296	−0·0002

mental results indicate the presence of a small constant negative error due apparently to some solubility of sodium chloride in the saturated solution of hydrogen chloride in alcohol, as well as to losses in manipulation. Unfortunately the error per cent cannot be lessened by working with larger amounts of the salts on account of the limited solubility of the chlorides in alcohol.

During the past two years the methods described above for precipitating potassium by aniline perchlorate, and then sodium chloride by hydrochloric acid gas, have been successfully used as a means of detecting the presence of these elements by the class in qualitative analysis in this laboratory. In order to lessen the amount of gaseous hydrogen chloride used, the sodium, after the removal of the potassium, is precipitated by means of sulphuric acid instead of hydrogen chloride, where possible. A few drops of a dilute solution of sulphuric acid in alcohol will generally precipitate even very small amounts of sodium as sodium sulphate, but if too much acid is added the acid sulphate is formed and dissolved in the alcohol. Hence, if no precipitate is obtained with sulphuric acid, gaseous hydrogen chloride is passed into the solution to saturation, precipitating the sodium as chloride practically completely.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *Prout's Hypothesis.*—This old idea that the atomic weights of the elements heavier than hydrogen are exact multiples of the latter has been elaborately discussed by William D. Harkins and Ernest D. Wilson in two articles entitled, "The changes of mass and weight involved in the formation of complex atoms," and "The structure of complex atoms. The hydrogen-helium system." Taking the first 26 atomic weights above hydrogen in the order of magnitude, it is found on the basis of hydrogen as unity that nearly all of them show negative variations from whole numbers. Thus, the atomic weight of helium is 3·97, lithium is 6·89, and boron is 10·91, which give the variations −0·03, −0·11 and −0·09 respectively. When these variations are calculated as percentages, the striking fact is observed that with the exception of Be, Mg, Si and Cl, which show positive variations, the average negative variation of 21 atomic weights is 0·77 per cent, while the six elements from boron to sodium show values of 0·77, 0·77, 0·70, 0·77, 0·77 and 0·77 per cent. The values of P, V, and Cr are 0·71, 0·77 and 0·77 per cent, while the others vary between 0·40 per cent for Al and 1·06 per cent for Fe. The negative deviation is, therefore, not a periodic but a constant one. The authors call this negative variation a *packing effect*, meaning that when several hydrogens are united to form a heavier atom there is a loss in weight amounting to about 0·77 per cent of the whole. When oxygen as 16 is taken as a basis for the atomic weights of the 21 elements under consideration their variations from whole numbers are very slight, as is well known. The "packing effect" occurs in the oxygen as well as in the others, so that in this case it is eliminated, and Prout's hypothesis in this modified form applies to these atomic weights. The deviation from whole numbers averages only 0·05 unit for the 21 elements, and the probability that such values should occur by accident is so slight as to be unworthy of consideration.

There are many points discussed by the authors in their interesting articles that will not be mentioned here, as it is intended to present only such features of the discussion as have a very direct bearing on Prout's hypothesis. No explanation is advanced in regard to the atomic weights of the elements magnesium, silicon and chlorine, which are exceptional among the lighter atomic weights in not approaching close to whole numbers, and in showing positive variations when hydrogen is used as unity. Further than this, the authors have found that the remaining 42 elements with heavier atomic weights, from nickel upward, show no tendency to approximate to whole numbers, since the average of their deviations is very close to 0·25 unit, which would be expected from variations governed by chance. No satisfactory explanation of this last circumstance is given, and it appears that Prout's hypothesis modified by the "packing effect" can be applied only to about one-third of the elements whose atomic weights are pretty accurately known, and that these are among the lighter atomic weights.—*Jour. Amer. Chem. Soc.*, xxxvii, 1367, 1383.

H. L. W.

2. *The Action of Chloroform upon Metallic Sulphates.*—A. Conduché has obtained interesting results by studying the action of chloroform vapor, carried along by means of a current of carbon dioxide, upon heated metallic sulphates. The reaction supplies a method for the production of anhydrous chlorides. The change is indicated by the formation of white vapors, and it takes place at a rather low temperature: 250° C for $CuSO_4$, 300° for $NiSO_4$ and $FeSO_4$, 350° for $MuSO_4$ and $PbSO_4$, 400° for $Al_2(SO_4)_3$, 450° for $MgSO_4$, 500° for $BaSO_4$, $CaSO_4$ and Na_2SO_4. Practically, however, a higher temperature is required to make the reaction complete, and on the other hand, the vapor of chloroform decomposes between 400° and 500° with the production of carbonaceous deposits, so that the chlorides are not obtained in a pure condition when the temperature used is too high. The reducing action of the chloroform may have an influence upon the chloride produced in case a metal forms two chlorides. For example, $CuSO_4$ yields pure $CuCl_2$ at 280-300°, while at about 400° CuCl is produced. In the cases of $FeSO_4$ and $Fe_2(SO_4)_3$ mixtures of $FeCl_2$ and $FeCl_3$ are always obtained, the proportions of which depend upon the temperature employed.—*Comptes Rendus*, clviii, 1180.

H. L. W.

3. *Explosives;* by Arthur Marshall. Large 8vo, pp. 624. Philadelphia, 1915 (P. Blakiston's Son & Co. Price, $7.50 net).—The author of this important work on the manufacture, properties, tests, and history of explosives, is the Chemical Inspector of the British Indian Ordnance Department. No comprehensive work on this subject has appeared in English within a period of 20 years, during which time very great changes and developments have taken place in the industry, so that the present book will undoubtedly supply a real want. The book treats the subject very fully and ably, it contains 137 illustrations, and gives a very interesting and useful account of this great branch of chemical industry.

H. L. W.

4. *Chemical Technology and Analysis of Oils, Fats, and Waxes;* by J. Lewkowitsch, edited by George H. Warburton. Vol. III, 8vo, pp. 483. London, 1915 (Macmillan and Co., Limited. Price, $6.50 net).—The present, third volume, completes the fifth edition of this important work, which has been entirely re-written and enlarged. The previous volumes have been favorably noticed already in this Journal, hence it is only necessary to point out that the present volume deals chiefly with manufacturing operations, and that among the important and interesting topics treated are edible oils and fats and their sub-

stitutes, lubricating oils and greases, hydrogenated fats, varnishes, the candle industry, soap manufacture, and glycerine manufacture. H. L. W.

5. *Annual Reports on the Progress of Chemistry for 1914.* 8vo, pp. 303. London, 1915 (Gurney & Jackson, London; D. Van Nostrand Company, New York).—This is the eleventh volume of these reports which are issued by the Chemical Society. It contains eleven articles dealing with the various branches of chemistry, among which radio-activity is included. Each of the articles has been prepared by a specialist in the subject discussed, and the book is a very useful one in furnishing concise and interesting accounts of the important results of investigations published during the year under consideration. H. L. W.

6. *X-Ray Band Spectra.*—As is well known, the negatives of X-ray spectra taken by de Broglie show very clearly two bands in the region of very short wave-lengths. These bands have sharp limits on the less refrangible side, they have never been resolved into lines, and they maintain their spectral positions unaltered when the material of the anticathode is changed. On account of these properties it has been suggested by the Braggs and Siegbahn that the two bands owe their origin to the silver and bromine in the photographic films. In testing this hypothesis E. Wagner has recently brought to light some interesting and important facts.

The spectrometer used was of the rotating crystal type and was especially designed to minimize the mechanical vibrations arising from the driving mechanism. The most novel feature of the system consisted in coupling segments of the axles with short pieces of rubber tubing. The angular speed was very uniform and amounted to about 10 degrees of arc per minute. Selected rock-salt crystals were used as space gratings, the natural cleavage planes containing the axis of rotation of the spectrometer table and being equidistant from the emergence slit of the lead collimator tube and the center of the photographic plate. The "hard" and "soft" X-ray tubes were provided with tungsten and platinum or palladium anticathodes respectively. The negatives obtained with exposures of seven or eight hours are very clear and sharp.

One horizontal strip of the 7-hr. negative obtained with a soft tungsten bulb shows three bands, the central image, and a number of metallic lines. The adjacent strip was produced simultaneously by the radiations which emerged from a sheet of aluminium $1{\cdot}4^{mm}$ thick which was placed 1^{cm} in front of the plate. The band of intermediate wave-length, which was very intense on the strip first mentioned, is not recorded on the second strip. The persistence and location of the least refrangible band show that it is the second order image corresponding to the band of shortest wave-length. The extreme bands were supposed to be due to silver and the intermediate band was ascribed to bromine. If this hypothesis is correct we should expect to find that a suitable metal would give rise to a similar band, if the metal (in the form of foil) were placed close to the sensitive film instead of being located in the gelatine film itself. Layers of pure tinfoil were pressed flat against the back of the photographic plate and exposures were made with the sensitive film turned away from the incident radiation. Under these circumstances the soft, secondary radiation starting in the tinfoil would be absorbed by the glass and thus prevented from confusing the negative. As anticipated, a tin band of slightly shorter wave-length than the supposedly silver band is a prominent feature of the photograph. The new band ends abruptly on its longer wave-length side and is similar in all respects to the three bands of the first negative. In order to decide whether the tin band was due to secondary Röntgen rays or to swift electrons, the last experiment was repeated under slightly different conditions. A sheet of aluminium foil, of such a thickness ($0{\cdot}1^{mm}$) as to absorb all corpuscular radiation but to readily transmit X-rays, was interposed between the tinfoil and the sensitive film. For sake of comparison, a longitudinal slot was cut in the aluminium screen. The tin band was of the same intensity behind the aluminium as on the unscreened strip of the negative. Therefore the tin band was due to the strong secondary or fluorescent Röntgen radiation, excited in the tin by the dispersed primary rays. The fact that the secondary rays give a continuous band instead of one or more homogeneous lines shows that the band corresponds to the entire spectral interval within which the fluorescent radiation can be excited. It is worthy of note that the intensity of the secondary radiation near the edge of the tin band was of the same order of magnitude as the intensity of the primary beam. Accordingly the primary rays must experience very strong absorption in the tin. When an experiment was performed with sheets of tin placed a few centimeters infront of the photographic plate, it was found that the absorption band had exactly the same edge and complementary intensity distribution as the fluorescent emission band. Having obtained this information about tin, it was easy for the investigator to show that the supposedly silver bands were really due to the silver in the photographic emulsion. A narrow strip of pure silver foil ($0{\cdot}013^{mm}$ thick) was placed at a distance of 1^{cm} before the plate and an exposure taken. The characteristic edge of the silver band disappeared almost completely and, for each wave-length, the selective absorption in the silver foil had produced precisely the complementary photographic action as the selective intensification of the silver inside the gelatine. Although Wagner has not yet demonstrated experimentally that the "bromine band" owes its origin to the presence of bromine in the sensitive film, nevertheless the preceding work leaves but little doubt as to the correctness of the hypothesis. It may be concluded, therefore, that the photographic action of Röntgen rays of very short wave-length is due to the highly selective fluorescence of the silver and bromine atoms. On the other hand, the ability of the plate to record radiations of longer wave-length than the bands (such as X-ray lines) depends upon the silver bromide molecules, just as for ordinary light.

In an earlier investigation Wagner found a close connection between the wave-length λ_A of the sharp edges of the bromine, silver, and tin bands and the wave-length λa of the corresponding fluorescence lines of Moseley's K-series. Moreover, conformable to the law of Stokes, the radiation of longest wave-length able to produce fluorescence was always more refrangible than the excited $K a$-line. Finally, the ratio $\lambda_A/\lambda a$ ("der Stokessche Sprung") was approximately constant. In addition to the three substances mentioned above the investigation has been extended by Wagner to the following metals, namely: cadmium, copper, iron, nickel and palladium. All of the relations between the wave-lengths were found to hold, and a number of new facts of theoretical significance were brought to light. For further details, however, the original paper must be consulted.—*Ann. d. Physik*, vol. xlvi, p. 868, March, 1915. H. S. U.

7. *Elements of Optics;* by GEORGE W. PARKER. Pp. 122, with 64 figures. London, 1915 (Longmans, Green, and Co.).—That the text is very elementary in character may be inferred from the following quotation, namely: "This little book is intended for those students whose knowledge of Mathematics is limited to an acquaintance with Elementary Geometry, the solution of Simple Algebraic Equations, and a few fundamental propositions in Trigonometry." The author's style is clear, and the material is so chosen as to be interesting as well as instructive. The method of rays is used throughout and the illustrative figures are printed as white lines on black background. A comparatively large number (106) of "exercises" for solution by the student are incorporated in the text and the answers are given at the end of the volume. The book is undoubtedly good, as far as it goes, but the impression of incompleteness is given by the unusually small number of topics discussed. Nothing is said, for example, about photometry, astigmatism, etc. H. S. U.

8. *Dielectric Phenomena in High Voltage Engineering;* by F. W. PEEK, JR. Pp. xv, 265, with 190 figures. New York, 1915 (McGraw-Hill Book Co.).—"It is the object of the author to give in this book the properties of gaseous, liquid and solid insulations, and methods of utilizing these properties to the best advantage in the problems of high-voltage engineering." "Much original work is given, as well as reference to other investigations." "The author's extensive research was made possible by facilities afforded by the Consulting Engineering Department of the General Electric Company . . ."

A general idea of the contents of the volume may be obtained from the titles of the chapters, namely: "The Dielectric Field and Dielectric Circuit (Mathematical Consideration); Visual Corona; Spark-over; Corona Loss; Corona and Spark-over in Oil and Liquid Insulations; Solid Insulation; The Electron Theory;

Practical Corona Calculation for Transmission Lines" ; and "Practical Considerations in the Design of Apparatus where Solid, Liquid and Gaseous Insulations Enter in Combination." The appendix (pages 238 to 256) comprises a large number of tables of numerical data pertaining to corona losses. The graphs and diagrams are clear-cut and the reproductions of photographs are excellent. In general, special attention seems to have been given to making the text as accurate, useful and practical as possible. Chapter VIII, on the electron theory, alone marks an exception. For example, on page 193 may be found the following slips : " . . . a wire-carrying current" ; "Each ion in a gas acts as nuclei . . ." ; "Ion is a general term used for . . . electrons. . . ."

H. S. U.

9. *The Radium-Uranium ratio in Carnotites;* by S. C. Lind and C. F. Whittemore. Bureau of Mines, Tech. Paper 88 (Mineral Tech. 6).—The authors have carried through an investigation of the carnotite of Colorado and Utah as to the radium-uranium ratio. The results obtained can best be given by quoting at length the summary with which the paper closes:

1. Samples of carnotite representing large quantities of ore (a few hundred pounds to several tons) show a radium-uranium ratio identical with that of pitchblende ($3{\cdot}33\times10^{-7}$); this ratio is also in accord with the value calculated from radiation data.

2. Samples from small quantities of ore (hand specimens up to a few pounds) tend to exhibit abnormal ratios. In one instance the ratio was as low as $2{\cdot}48\times10^{-7}$, and in another as high as $4{\cdot}6\times10^{-7}$.

3. The most plausible explanation for these abnormal ratios seems to be that of transposition of radium within the ore bed, producing local differences which are equalized in large samples.

4. The "emanating power" of carnotite is high, and varies from 16 to 50 per cent.

5. In order to obtain concordant results by the Boltwood emanation method it was found desirable to determine the emanation liberated by solution in the same sample from which the emanating power had just been determined, thus making the two determinations strictly "complementary."

6. Radium may be easily determined in one operation by the emanation method, either by solution or by ignition from tubes in which it has been sealed for one month to reach equilibrium.

7. In contrast with the success of the solution and the ignition methods for de-emanating carnotite, the method of fusion with sodium and potassium carbonates and the fusion-and-solution method both gave low results and were abandoned.

II. GEOLOGY AND MINERALOGY.

1. *Climate and Evolution;* by W. D. Matthew. Ann. New York Acad. Sci., vol. xxiv, 1915, pp. 171-318, figs. 1-33.—The title of this important work does not convey the intent of the author and should have been "The geographic dispersal of

animals as affected by climate and evolution" or "The theory of land bridges as negated by climate and evolution." As is well known, the author is an ardent believer in the permanency of continents and ocean basins as they now exist, though the study in hand aims to prove the hypothesis for Cenozoic time only. However he states that "If the distribution of animals be interpreted along the lines here advocated, there is no occasion for a Gondwana Land even in the Paleozoic" (191). The reviewer thinks his conclusion sound when restricted to the Cenozoic, but to say there was no Gondwana in early Mesozoic time, and especially none in Permian time, is to drag into this painstaking and most excellent study an unnecessary and unproved conclusion.

The work is replete with facts and new ideas regarding the dispersal of animals (mainly mammals), interpreted on the basis of periodic changes of climate from moist, uniform, and warm to arid, to zonal, and glacial ones. The writer seeks to prove that the present distribution of life in the various continents can be best explained by radial dispersal from Holarctic centers with variable climates (Europe, Asia, North America) into the peripheral lands (South America, Africa, Australasia). His main principle of dispersal is that in the evolution of a race "it should be at first most progressive at its point of original dispersal, and it will continue this progress at that point in response to whatever stimulus originally caused it and spread out in successive waves of migration, each wave a stage higher than the previous one. At any one time, therefore, the most advanced stages should be nearest the center of dispersal, the most conservative stages farthest from it. It is not in Australia that we should look for the ancestry of man, but in Asia" (180). Finally our knowledge of fossil land animals is almost wholly of those of the lowlands, with but rare glimpses of an upland form (274).

As the oceanic islands have life derived from the adjacent continents, the author explains the arrival of this life over sea as due to natural rafts. He argues that for every raft seen a hundred have probably drifted out unseen, and if we concede that 1000 have probably occurred in three centuries, then 10,000,000 (by an error he states 30,000,000) would have occurred in the Cenozoic. He further estimates that only 1,000,000 will have living animals upon them, of these only 10,000 will reach land, and in only 100 of these cases will the species establish a foothold. This is quite sufficient to cover the dozen or two of Mammalia on the larger oceanic islands" (206–207). Undoubtedly there is some truth in these figures, especially for very small animals, but such rafts can hardly have been a marked factor in the dispersal of land animals.

Doctor Matthew does not believe in the fracturing of continents as evidenced by the separation of Madagascar from Africa, nor does he hold to the idea that where mountains are now seen to terminate abruptly facing the ocean (as in the Maritime Provinces of Canada, in Great Britain, Belgium and France, such coasts being known as Rias coasts) they have sunk into the depths. Regarding the continental shelf being "so marked, obvious and universal a feature of the earth's surface that it affords the strongest kind of evidence of the antiquity of the ocean basins and the limits beyond which the continents have not extended" (308–309), the reveiwer holds that the present continental shelf is of modern construction, certainly of late Cenozoic making, and simply represents the land wash within the zone of wave and tidal action. With every shrinkage of the earth and subsidence of the oceanic areas the margins of the continents are locally or regionally warped downward and new continental shelves are developed upon the sunken areas. The possible increase in the amount of water during geologic time is left out of consideration (309) and nowhere is there a word as to why most of Africa and eastern South America have broken-down coasts instead of uplifted and folded margins.

The reviewer heartily recommends the work to paleontologists and zoogeographers, as the author is believed to be sound in his general premises regarding the distribution of land animals during Cenozoic time. Some years ago the reviewer undertook a similar study, starting out with the theory that Africa and South America were still united in early Tertiary, but gradually came to the conclusion that these lands had been broken through by the Atlantic in Lower Cretaceous (Upper Comanchian) times. C. S.

2. *Publications of the United States Geological Survey*, George Otis Smith, Director.—Recent publications of the U. S. Geological Survey are noted in the following list (continued from vol. xxxix, pp. 316–318):

Topographic Atlas—Sixty-seven sheets.

Professional Papers.—No. 88. Lavas of Hawaii and their relations; by Whitman Cross. Pp. 97; 4 pls. See p. 88.

No. 90. Shorter Contributions to General Geology. I. The Stratigraphy of the Montana Group with special reference to the position and age of the Judith River Formation; by C. F. Bowen. Pp. 95–153; 1 pl. J. The Cretaceous-Eocene contact in the Atlantic and Gulf Coastal Plain; by Lloyd W. Stephenson. Pp. 155–182; 9 pls., 8 figs. K. The History of a portion of Yampa River, Colorado, and its possible bearing on that of Green River; by E. T. Hancock. Pp. 183–189; 2 pls. L. The Inorganic constituents of Echinoderms; by F. W. Clarke and W. C. Wheeler. Pp. 190–199.

No. 95–A. The composition of muds from Columbus Marsh, Nevada; by W. B. Hicks. Pp. 11, 1 fig.

Bulletins.—Nos. 559, 560, 563, 567. Results of Spirit Leveling. R. B. Marshall, Chief Geographer. No. 559. Michigan, 1911 and 1913. Pp. 79; 1 pl. No. 560. Minnesota, 1897–1914. Pp. 190; 1 pl. No. 563. Maryland, 1896 to 1911, inclusive. Pp. 80; 1 pl. No. 567. Idaho, 1896–1914. Pp. 130; 1 pl.

No. 582. Mineral Deposits of the Santa Rita and Patagonia Mountains, Arizona; by FRANK C. SCHRADER, with contributions by JAMES M. HILL. Pp. 373; 25 pls., 46 figs.

No. 589. The calcite marble and dolomite of Eastern Vermont; by T. NELSON DALE. Pp. 66; 2 pls., 11 figs.

No. 594. Some mining districts in Northeastern California and Northwestern Nevada; by JAMES M. HILL. Pp. 200; 19 pls., 4 figs.

No. 596. Geology and coal resources of North Park, Colorado; by A. L. BEEKLY. Pp. 121; 12 pls., 1 fig.

No. 580. Part I–L. Salines in the Owens, Searles, and Panamint Basins, Southeastern California; by HOYT S. GALE. Pp. 251–323; 3 pls., 31 figs. Part I–P. Publications by Survey authors on metal and non-metals except Fuels. Compiled by ISABEL P. EVANS. Pp. 413–445.

No. 581. 1913. Part II–E. The Coalville Coal Field, Utah; by CARROLL H. WEGEMANN. Pp. 161–187; 6 pls.

No. 620–A. A gold-platinum-palladium lode in Southern Nevada; by ADOLPH KNOPF. Pp. 18; 1 pl., 1 fig.

WATER SUPPLY PAPERS.—Nos. 312, 331, 353, 354. Surface Water Supply of the United States; prepared in coöperation with the respective States. No. 312. 1911. Part XII. North Pacific coast drainage Basins; by F. F. HENSHAW and others. Pp. 706; 4 pls. No. 331, 1912. Part XI. Pacific Coast Basins in California; by H. D. MCGLASHAN and G. C. STEVENS. Pp. 442; 2 pls. Nos. 353, 354, 1913. Part III. Ohio River Basin; by A. H. HORTON, and others. Pp. 264; 5 pls. No. 354. Part IV. St. Lawrence River Basin; by W. G. HOYT, and others. Pp. 136; 2 pls.

No. 340. Stream-Gaging Stations, etc., 1885–1913 (compiled by B. D. WOOD). F. Part VI. Missouri River Basin. Pp. viii, 63–81. G. Part VII. Lower Mississippi River Basin. Pp. viii, 83–93. Part VIII. Western Gulf of Mexico drainage Basins. Pp. viii, 95–104. Part IX. Colorado River Basin. Pp. viii, 105–116. Part X. The Great Basin. Pp. viii, 117–129.

No. 345–H. Ground-Water Resources of the Niles Cone and adjacent areas, California; by W. O. Clark. Pp. iv, 127–168; 9 pls., 16 figs. I. Gazetteer of surface waters of Iowa; by W. G. HOYT and H. J. RYAN. Pp. 169–225.

No. 375–A. Ground Water for irrigation in the Sacramento Valley, California; by KIRK BRYAN. Pp. 49; 2 pls., 6 figs.

Nos. 349, 350, 367, 368. Profile Surveys prepared under the direction of R. B. MARSHALL, Chief Geographer. No. 349. Willamette River Basin, Oregon. Pp. 8; 3 pls. No. 350. Bear River Basin. Idaho. Pp. 7; 1 pl. No. 367. Missouri River from Great Falls to Three Forks, Montana. Pp. 8; 1 pl. No. 368. Wenatchee River Basin, Washington. Pp. 7; 1 pl.

No. 338. Springs of California ; by GERALD A. WARING Pp. 410; 13 pls., 4 figs.

No. 341. Underground Waters of the coastal plain of Georgia; by L. W. STEPHENSON and J. O. VEATCH. And a discussion of the quality of the Waters; by R. B. Dole. Pp. 539; 21 pls., 4 figs.

No. 343. Geology and Water Resources of Tularosa Basin, New Mexico; by O. E. Meinzer and R. F. Hare. Pp. 317; 19 pls., 51 figs.

No. 365. Ground Water in Southeastern Nevada; by Everett Carpenter. Pp. 86, 5 pls., 3 figs.

3. *The United States Bureau of Mines*, Joseph A. Holmes, Director.—The following Bulletins have been issued since the last summary (vol. xxxix, p. 224):

No. 80. A primer on explosives for metal miners and quarrymen; by Charles E. Munroe and Clarence Hall. Pp. 125; 15 pls., 17 figs.

No. 81. The smelting of copper ores in the electric furnace; by D. A. Lyon and R. M. Keeney. Pp. 77; 6 figs.

No. 84. Metallurgical smoke; by Charles H. Fulton. Pp. 94; 6 pls., 15 figs.

No. 87. Houses for mining towns; by Joseph H. White. Pp. vi, 58; 8 pls., 9 figs.

No. 88. Petroleum Technology 20. The condensation of gasolene from natural gas; by G. A. Burrell, F. M. Seibert, and G. G Oberfell. Pp. 106; pls. vi, 18 figs.

No. 90. Law Serial 3. Abstracts of current decisions on mines and mining, December, 1913, to September, 1914; by J. W. Thompson. Pp. xvii, 175.

Numerous Technical Papers have also been published. See p. 83.

4. *Canada, Department of Mines.*—The following are some of the more important of recent publications (see vol. xxxix, 481).

(1) *Geological Survey Branch;* R. W. Brock, Director.

Memorial.—No. 56. Geology of Franklin Mining Camp, British Columbia ; by Charles W. Drysdale. Pp. vii, 246 ; 23 pls., 16 figs.

Memoir 57. Corundum, its occurrence, distribution, exploitation, and uses; by Alfred E. Barlow. Pp. vii, 377; 2 maps, 20 pls. This is a highly valuable discussion of a subject of prime interest alike from the theoretical and the technical standpoints; a notice appears later.

No. 59. Coal Fields and Coal Resources of Canada; by D. B. Dowling. Pp. 174 ; 7 maps, 9 figs.

No. 61. Moore Mountain District, Southern Alberta (second edition) ; by D. D. Cairnes. Pp. 62 ; 2 maps, 1 fig.

No. 65. Clay and Shell Deposits of the Western Provinces, Part IV ; by H. Ries. Pp. 83 ; 8 pls., 18 figs. No. 66. The same, Part V ; by J. Keele. Pp. 74 ; 8 pls.

Also the Mining Museum Bulletins :

No. 11. Physiography of the Beaverdell map-area, etc.; by L. Reinecke.

No. 12. On *Eoceratops canadensis*, gen. nov., with remarks on other genera of Cretaceous horned Dinosaurs ; by L. M. Lambe.

No. 14. Glacial Drift in the Magdalen Islands ; by J. W. Goldthwait.

(2) *Mines Branch;* EUGENE HAANEL, Director.—Summary Report for the calendar year ending December 31, 1913. Pp. x, 214; 51 pls., 24 figs., 1 map.

Annual Report on the Mineral Production of Canada during the calendar year 1913. JOHN MCLEISH, Chief of the Division of Mineral Resources and Statistics. Pp. 363.

Bulletin No. 9. Investigation of the Peat Bogs and Peat Industry of Canada 1911–12; by A. V. ANREP. Pp. vii, 47; 29 pls., 6 figs., 11 maps. No. 10. Notes on Clay Deposits near McMurray, Alberta; by SYDNEY C. ELLS. Pp. 15.

Report on the Non-metallic minerals used in the Canadian manufacturing industries; by HOWELLS FRÉCHETTE. Pp. viii, 199.

Peat, Lignite, and Coal: their value as fuels, etc.; by B. F. HAANEL. Pp. xv, 261, 19 pls., 39 figs., 20 tables.

Petroleum and Natural Gas Resources of Canada. In two volumes. Vol. I; by FREDERICK G. CLAPP and others.

Preliminary Report on the bituminous sands of Northern Alberta; by S. C. ELLS. Pp. iv, 92, 55 pls., 5 figs., 1 map.

5. *Lavas of Hawaii and their Relations;* by WHITMAN CROSS. Prof. Paper 88, U. S. Geol. Survey, 1915, pp. 97, 4 pls.—This paper is not only of local interest in furthering our knowledge of the petrology of the Hawaiian group, but also an important contribution to the general literature of the subject. It represents the results of a considerable amount of work in the field by the author in studying the occurrences of the rocks composing the volcanoes, and in the collection of material, in the petrographical investigation of this material as well as that collected by others, and of a large number of chemical analyses. The precise data thus assembled are of great and permanent value as a contribution toward a better understanding of the petrogenesis of Hawaiian lavas.

The different islands are taken up separately and the rocks occurring upon them described. It would be beyond the limits of this notice to give these details, but it may be said of the rocks as a whole that while the author finds that basalts of the calcic series are the dominant types, yet occurrences of rocks of clearly alkalic character are well represented, with some of intermediate nature. In regard to the origin of these rocks, Cross assumes that they have been formed by differentiation from a general parent magma of the composition of a normal calcic basalt, and that during the active period of each volcano differentiation was seldom if ever able to produce partial magmas of extremely salic or femic character. This might be due to short periods of quiet in the magma chamber insufficient to permit of much differentiation. He is not inclined to view the sinking of crystals as a dominant factor in the process, though this may have played some part. With decreasing activity and, perhaps, some contraction and limitation of magma chambers there was more differentiation with correspondingly more salic and femic lavas. In the final period of dying activity, when parasitic eruptions followed, occurred the most extensive differentiation affording the complementary alkalic felsic and mafic types. Every petrographer will find these discussions of the petrogenesis and classification of the rocks of great interest, based as they are upon such accurate data and presented so clearly. L. V. P.

6. *Brief Notices of some recently described Minerals.*—Barthite is a zinc-copper arsenate, described by W. Henglein and W. Meigen, from Guchab in the Otavi mountains, German South West Africa. It occurs as a crystalline incrustation on quartz crystals which form druses in a reddish dolomite. Hardness 3; specific gravity 4·19 ; color grass-green ; luster greasy. An analysis gave :

As_2O_5	P_2O_5	ZnO	CuO	H_2O	insol.
64·0	1·0	23·3	8·5	3·2	1·1 = 101·1

For this the formula $3ZnO.CuO.3As_2O_5.2H_2O$ is calculated.—*Centralbl. Min.*, 353, 1914.

Ussingite is a new silicate, described by O. B. Böggild, from the remarkable locality at Klangerdluarsuk, Greenland. It is referred to the triclinic system on the basis of cleavage fragments. Hardness 6 to 7; specific gravity 2·50; luster vitreous to pearly; color violet-red. An analysis by Chr. Christensen gave:

SiO_2	Al_2O_3	Na_2O	H_2O	
58·74	17·73	19·91	4·19	= 100·57

This leads to the formula $HNa_2Al\ (SiO_3)_3$.—*Zs. Kryst.*, liv, 120, 1914.

Faratsihite is a hydrated ferric silicate described by A. Lacroix, from Faratsiho, Madagascar. It occurs in masses of a yellow color, resembling nontronite. Under the microscope it shows a crystalline structure like that of kaolinite, being made up of aggregates of minute hexagonal scales. An analysis gave:

SiO_2	Al_2O_3	Fe_2O_3	H_2O(105°)	H_2O(red heat)	X
41·60	22·68	15·22	5·71	13·02	1·44 = 100·20

Here $X = FeO$ 0·54, MgO 0·11, CaO 0·60, Na_2O 0·16, K_2O 0·22, TiO_2 0·13, P_2O_5 0·21. The formula deduced is $H_4(Al, Fe)_2\ Si_2O_9$, and it may be regarded as a kaolinite in which part of aluminium is replaced by ferric iron.—*Bull. Soc. Fr. Min.*, xxxvii, 231.

Speziaite is a kind of amphibole described by L. Colomba, from the pyroxenite of Riondello, Traversella. It occurs in fibrous and acicular forms with cleavage angle of 55° 30′ to 56°; color green, pleochroic; the angle $c \wedge c = +23°$ to 24°. An analysis gave:

SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	Na_2O	K_2O	H_2O
36·21	0·79	34·57	3·56	0·67	10·53	7·87	4·08	0·93	0·50 = 99·71

The calculated formula is that of an orthosilicate $5Fe_4(SiO_4)_3.12\ (Ca, Mg, Fe, Na_2, H_2)\ SiO_4$. — *Atti Accad. Sci., Torino*, xlix, March, 1914.

Lublinite is described by R. Lang as a monoclinic modification of calcium carbonate forming the soft earthy aggregate called "rock milk"; the occurrence examined was from the Diessener valley near Horb on the Neckar. A similar form, also earthy and made up of microscopic needles, from the Adams valley near Brünn has been studied by O. Mügge. The conclusion reached by him is that there is no reason for assuming the existence of a new modification of $CaCO_3$; the peculiar characters being probably due to pseudomorphism after organic remains.—Lang, *N. Jahrb. Min.*, Beil. Bd., xxxviii, 121, 1914; Mügge, *Centralbl. Min.*, 673, 1914; Lang, *ibid.*, 298, 1915.

HEWETTITE, METAHEWETTITE and PASCOITE are hydrous calcium vanadates described by Hillebrand, Merwin and Wright. *Hewettite* was obtained by D. F. Hewitt, at the vanadium locality of Minasragra, Peru. It occurs in deep red lumpy aggregates of microscopic crystal needles; it is derived from the oxidization of the sulphide patronite. Specific gravity 2·55; melts easily to a dark red liquid; slightly soluble in water.

A similar red ore of vanadium, *Metahewettite*, has been found in the Paradox valley, Montrose Co., Colo., and elsewhere over a wide area extending into Utah. For these two minerals the same composition, $CaO.3V_2O_5.9H_2O$ is obtained, assuming the maximum content of water at room temperatures; but both are found to be very sensitive to atmospheric changes of humidity. The course of progressive dehydration over sulphuric acid has been minutely studied and the marked difference in this regard is the reason for the difference in name given.

Pascoite, also from Minasragra, occurs in clusters of crystalline (monoclinic ?) grains of a dark orange color. Hardness 2·5; specific gravity 2·457. It melts to a deep red liquid and dissolves easily in water. Analysis gave:

V_2O_5	MoO_3	CaO	H_2O 100 −	H_2O +	undet.
64·6	10·3	12·6	13·8	7·8	[0·9] = 100.

The calculated formula is $2CaO.3V_2O_5.11(?)H_2O$. — *Proc. Am. Phil. Soc.*, liii, 31, 1914.

PINTADOITE and UVANITE are new vanadium minerals from Utah described by Hess and Schaller. *Pintadoite* forms a thin green efflorescence on the sandstone cliffs of the Canyon Pintado, San Juan Co. An analysis (Schaller) gave:

V_2O_5	CaO	H_2O	
42·4	22·6	35·0	= 100.

The calculated formula is $2CaO.V_2O_5.9H_2O$.

Uvanite is similar to carnotite in appearance and occurrence, but has a brownish yellow color; it has been found only at Temple Rock, Emery Co. An analysis (Schaller) gave:

V_2O_5	P_2O_5	As_2O_5	UO_3	CaO	MgO	K_2O	H_2O	insol.
37·70	0·06	0·05	39·60	1·73	0·04	0·30	18·28	1·24 = 99·00.

After the deduction of impurities, the formula $2UO_3.3V_2O_5.15H_2O$ is calculated.—*Jour. Washington Acad. Sci.*, iv, 576, 1914.

7. *An Amateur's Introduction to Crystallography;* by Sir WILLIAM PHIPSON BEALE. Pp. vi, 220, figs. 126. London, 1915 (Longmans, Green and Co.).—This book, as its title indicates, is intended for the use of the non-scientific reader but is nevertheless quite scientific in its treatment. By a somewhat novel method the subjects of crystal axes, indices and symmetry are introduced and illustrated. A brief discussion of the different crystal classes follows. In appendices more detailed descriptions of the methods of crystal calculation and drawing are given. The book is well illustrated. W. E. F.

8. *Die 32 krystallographischen Symmetrieklassen und ihre einfachen Formen;* by E. A. WÜLFING. Pp. 48, figs. 260, pls. viii. Berlin, 1914 (Gebrüder Borntraeger).—This is a second edition of the work, the first having been issued in 1895. The text, now added to the original work, includes brief discussions of crystal symmetry, the division of crystal forms into the thirty-two classes and of the simple forms characteristic of these classes. The tables, which are bound up separately in a small atlas, illustrate diagrammatically the matter of the text. W. E. F.

9. *Annual Tables of Constants and Numerical Data. Chemical, Physical and Technological.* Vol. iii. Chapter on Crystallography and Mineralogy, pp. 425–446; by L. J. SPENCER. Published by Gauthier-Villars et Cie, Paris and the University of Chicago Press, Chicago, 1914.—This is a single chapter of an important scientific publication designed to summarize yearly the new data of physical science. The present volume, No. III, covers the year 1912. The mineralogical chapter gives in brief form new mineral analyses, new crystal forms and axial ratios, new determinations of optical constants, of specific gravities, etc. It summarizes also the crystallographic and optical work done on artificial inorganic and organic compounds.

W. E. F.

III. BOTANY.

1. *Transpiration and the Ascent of Sap in Plant;* by HENRY H. DIXON. Pp. viii, 216, 30 figs. London, 1914 (Macmillan and Co.).—The valuable and original researches of Professor Dixon on the complex phenomena connected with the movement of sap in plants are here brought together in connected form. He looks upon transpiration as something more than a mere physical process and considers that an active excretion of water by the green cells is involved. In this way a high osmotic pressure is developed in the cells, sometimes amounting to over 20 atmospheres. He considers further that a continuity is maintained between the liquids in the green cells and those in the absorbing cells of the root by means of the liquids in the tracheids and other conducting elements of the stem and root; and he lays a great deal of emphasis on the cohesive or tensile strength of this

continuous liquid column. In some cases, according to his estimates, this strength exceeds 200 atmospheres. The high pressure maintained in the green cells by transpiration is transmitted through this liquid column but is clearly insufficient to rupture it, and in this way the upward passage of the sap is assured. Some of the most interesting of the experiments described by the author are those connected with the determination of the osmotic pressures in cells. They are based on the relationship which exists between the freezing point of a solution and its osmotic pressure, and in the determination of the freezing point an exceedingly delicate thermo-electric method has been employed. Professor Dixon's experiments and conclusions are of much importance and throw a great deal of light on one of the most difficult problems in plant physiology. A. W. E.

2. *A Manual of Weeds; with descriptions of all of the most pernicious and troublesome Plants in the United States and Canada, their habits of growth and distribution, with methods of control;* by Ada E. Georgia. Pp. xi, 593, 386 figs. New York, 1914 (The Macmillan Company).—The main purpose of the present work is to enable the growers of useful and ornamental plants to recognize and combat the numerous weeds which infest farms and gardens. The introductory chapters deal with general statements about weeds, about the financial loss which they cause, about the ways in which they disseminate themselves, and about the use of chemical herbicides. The body of the book, however, is devoted to full descriptions of individual weeds, and to definite methods of controlling them. The author gives in each case the botanical name of the weed, the English name or names, and tabulated information about the time of blooming, the time of seeding, the geographical distribution, and the habitat. The descriptions, although written in semi-popular language, are clear and accurate, and the numerous figures which accompany them should help make the determination of the weeds an easy task. The concluding pages give a bibliography, a list of poisonous plants, and a glossary of botanical terms. Miss Georgia's volume is issued in the series of Rural Manuals edited by Professor L. H. Bailey, but it will be found useful not only to those for whom it was written but also to those interested in weeds from a botanical standpoint. A. W. E.

3. *Plant-Breeding;* by L. H. Bailey. New edition revised by Arthur W. Gilbert. Pp. xviii, 474, 113 figs. New York, 1915 (The Macmillan Company).—As stated in the historical introduction the first edition of Plant-Breeding was published in 1895, and the present thoroughly revised edition is the fifth. The topics treated, which will give some idea of the scope of the volume, are the following: variation, mutation, hybridization, heredity, methods of crossing plants, and the forward movement of plant breeding. The discussion of variation and of the important part which it plays in originating new varieties is accompanied by a wealth of illustrative material and is especially

to be recommended. The body of the work is followed by five appendixes, which include a glossary, a list of plant-breeding books, a list of periodicals, a bibliography of references related to plant-breeding, and a series of laboratory exercises.

A. W. E.

4. *Fundamentals of Plant-Breeding;* by JOHN M. COULTER, Pp. xiv, 347. New York 1914 (D. Appleton and Company).—The present book aims to give a thoroughly modern account of evolution and heredity as applied to plant-breeding and agriculture in general. It describes clearly the theories of variation, natural selection and mutation, it reviews the recent work done in genetics, and it gives in detail the methods to be employed in securing resistance to drought and to disease. Chapters on forestry and on the work done by departments of agriculture both in this country and abroad are likewise included. The work presents in a graphic way the remarkable advances in plant-breeding which have been made possible by the scientific study of heredity and related topics, and it outlines some of the results which may be expected in the future. A. W. E.

5. *The Principles of Fruit-growing, with applications to practice;* by L. H. BAILEY. 20th edition, completely revised. Pp. xiv, 432, 186 figs. New York. 1915 (The Macmillan Company).—The original edition of this handbook was published in 1897, and the appearance of twenty editions within less than twenty years gives evidence of its great popularity. Although most of the book relates to the larger fruits of northern climates, especial attention being given to the laying out and care of orchards, the smaller fruits are by no means neglected. The information given is thoroughly practical in its nature and is designed primarily for those who raise fruit on a commercial basis. A. W. E.

IV. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *The Carnegie Foundation for the Advancement of Teaching. Ninth Annual Report of the* President, HENRY S. PRITCHETT, and of the Treasurer, ROBERT A. FRANK. Pp. vi, 154. New York City, October, 1914 (issued in June, 1915).—The total endowment of the Carnegie Foundation at the close of the last fiscal year amounted to $14,130,000, to which is to be added $1,250,000 specifically devoted to the division of Educational Enquiry. Of the general income of the year,—nearly $700,000,—$635,000 was devoted to retiring allowances and widows' pensions, while $26,500 was carried to surplus. The Educational Division had an income of $50,350, of which all was expended in its work except some $3,320. During the year 29 retiring allowances and 15 widows' pensions were granted, the average grant being $1,648. The total number of allowances now in force is 332, and of widows' pensions 100. There have been granted 595

allowances since the beginning, the expenditure for this purpose being $3,551,000.

The details in regard to the work of the Foundation are always interesting, but even more the discussions given to the special topics with which it is concerned. This is particularly true of the extended remarks by the President on the subject of pensions in general. The movement in the direction of teachers' pensions has progressed rapidly and thirteen of the states now have such systems ; it is shown, however, that most of these are radically faulty in their provisions for the future, and only that of Massachusetts deserves particular commendation. Industrial pensions are also briefly considered, and further the scandalously extravagant system of federal war pensions. Much attention is given in the report to the subject of medical schools, to which the Foundation has already contributed so largely. The radical change accomplished in the country since Dr. Abraham Flexner's critical report was published in 1912 (vol. xxxiv, 96) proves what can be accomplished by throwing the light of day into dark corners of the educational world.

The most important recent work done by the division of Educational Enquiry is that in the study of legal education, which has led to the publication of Bulletin No. 8 by Professor Redlich of Vienna, published some months since (see vol. xxxix, 611). The study of education in Vermont is also spoken of at length ; the bulletin on this subject (No. 7) was issued a year since (vol. xxxvii, 564).

2. *Publications of the Carnegie Institution of Washington.*—Recent publications of the Carnegie Institution are noted in the following list (continued from vol. xxxviii, p. 489):

No. 203. A study of prolonged fasting ; by FRANCIS G. BENEDICT. Pp. 416; 5 pls., 47 figs.

No. 204. The water-relation between plant and soil; by B. E. LIVINGSTON and L. A. HAWKINS. The water-supplying power of the soil as indicated by osmometers; by H. E. PULLING and B. E. LIVINGSTON. Pp. 49–83; 2 figs., 13 tables.

No. 205. Genetic studies on a Cavy species cross; by J. A. DETLEFSEN, with a preparatory note by W. E. CASTLE. Pp. 134; 10 pls.

No. 210. The Absorption Spectra of Solutions as studied by means of the Radiomicrometer; by HARRY C. JONES and COLLABORATORS. Pp. 202; 58 figs., 50 tables.

3. *The Crocker Land Expedition.*—A committee of the American Museum of Natural History, Prof. Henry Fairfield Osborn chairman, calls (May 20) for contributions toward the expense involved in bringing home the staff of the Crocker Land—or George Borup Memorial—Expedition, and in clearing up all outstanding obligations connected with it. A sum of $16,000 is needed to accomplish these ends and the same degree of liberality shown in earlier contributions for this Expedition is to be looked for now. It will be remembered that the sudden death of

the leader, Mr. George Borup, caused a postponement in its departure till 1913, when it left New York under the leadership of Mr. Donald B. MacMillan. The grounding of their vessel in the Straits of Belle Isle, in July, 1913, involved an expense of some $11,000, which explains a considerable part of the large sum now needed. The "George B. Cluett," the hospital and supply auxiliary schooner belonging to the Wilfred T. Grenfell Association, has been chartered and will proceed to Etah next summer and bring the members of the Expedition and their collections back to New York.

Checks should be made payable to the American Museum of Natural History and sent to the chairman of the committee in charge.

4. *Spencer Fullerton Baird. A Biography, including selections from his correspondence with Audubon, Agassiz, Dana, and others;* by William Healey Dall. Pp. i-xvi, 1-462, with 19 illustrations. Philadelphia and London, 1915 (J. B. Lippincott Company).—Spencer Fullerton Baird (1823–1887), father of the U. S. National Museum, the U. S. Commission of Fish and Fisheries, and the Marine Biological Laboratory at Wood's Hole, received his B.A. degree from Dickinson College, Carlisle, Pennsylvania, when he was seventeen years of age. Even at this time he was an industrious collector of birds and in correspondence with Audubon about a new species of flycatcher; long before his call to the Smithsonian Institution he was known to all naturalists in the United States. At the age of twenty-four, Baird was apprised by James D. Dana of the possibilities at Washington, and by him recommended to Henry, then secretary of the Smithsonian Institution, as keeper of the natural history cabinet. However, because of difficulties in erecting the building and because of shortage of funds, the appointment of Baird as assistant secretary did not come until July 5, 1850. For thirty-seven years thereafter he was intensely active in upbuilding American natural history and in laying the foundations which led to the establishing of many of the scientific departments of the Government bureaus at Washington.

The present biographer of Baird, Doctor Dall, became acquainted with him in 1862, and in 1865 was attached to the staff of the Smithsonian Institution, where he is still actively at work. He is, therefore, well qualified to be Baird's historian and to tell us how he lived and worked, with glimpses of his relations to his contemporaries, to the promotion of science, and to great public services. We are here also introduced to nearly all of the pioneer American naturalists, and told how the Smithsonian Institution came to be through the munificence of the Englishman, James Smithson, and how Baird, appointed its assistant secretary at an annual salary of $1500, gradually developed the U. S. National Museum and the Commission of Fisheries. These great institutions were being built up with little money and scant sympathy from the Government, and we learn that the Commission of Fish and Fisheries was started in 1870 with a grant of $100 and the use of the sloop yacht "Mazeppa," loaned by the New Bedford Custom House.

It is interesting to note that this biography of a great and sympathetic man is written by one who has himself given fifty years to the public service in science. C. S.

5. *Publications of the British Museum of Natural History.*—The following volumes have recently been issued (see vol. xxxix, p. 325 and earlier).

Catalogue of the Lepidoptera Phalænæ in the British Museum. Supplement. Volume I. Plates I–XLI.—This volume of plates, admirable in its execution both as to drawing and reproduction, belongs to the volume of text already noticed (l. c.).

A Revision of the Ichneumonidæ with descriptions of new genera and species. Part IV. Tribes Joppides, Banchides and Alomyides; by CLAUDE MORLEY. Pp. xii, 167.—This third part of the revision of the Ichneumonidæ by Mr. Morley embraces three additional families. A colored plate of *Joppa nominator*, by Mr. Robert Stenton, accompanies the volume.

The Syrphidæ of the Ethiopian Region, with descriptions of new genera and species; by Professor MARIO BEZZI. Pp. 146; 28 figs.—The collections of African Syrphidæ in the British Museum, received from the Imperial Bureau of Entomology, are remarkably rich and complete; they form the basis of this study by Prof. Bezzi. Some sixty new forms are described, making the whole number of species from this region 249; the family numbers some 2300 species, distributed over all parts of the world.

Report on Cetacea stranded on the British Coasts during 1914; by S. F. HARMER. Pp. 16, 4to; 1 text fig., 3 maps.—It is remarkable how many stranded whales are recorded from the shores of Great Britain. In 1914, up to August, some 43 had been noted; after that date the record was largely interrupted by the war. Of the total number of Cetaceans noted the larger part could be definitely determined as to species.

Instructions for Collectors: No. 12. Worms. Pp. 23; 17 figs. —The instructions contained in this pamphlet have been drawn up by Mr. H. A. Baylis, assistant in the department of zoology.

6. *The Rumford Medal of the American Academy of Arts and Sciences.*—It has been recently announced that the Rumford medal of the American Academy has been awarded to Dr. Charles G. Abbot, director of the Astro-physical observatory of the Smithsonian Institution. This medal, established through a donation from Count Rumford (Benjamin Thompson), in 1796, to the Academy, is annually given for researches in light and heat.

OBITUARY.

SIR ARTHUR HERBERT CHURCH, the veteran English chemist and mineralogist, died on June 2 at the age of eighty-one years.

DR. HUGO MÜLLER, president at one time of the London Chemical Society, died on May 23 at the age of eighty-one years.

DR. AKSEL S. STEEN, director of the Norwegian Meteorological Institute, died on May 10 at the age of sixty-six years.

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FOURTH SERIES

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AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

Art. VIII.—*The Igneous Origin of the "Glacial Deposits" on the Navajo Reservation, Arizona and Utah*; by Herbert E. Gregory.

Introduction.

The lowest recorded level reached by Pleistocene glaciers of Utah and Arizona south of Lat. 40° is 8500,[*] and it was therefore a matter of considerable interest when glacial deposits were reported from the Chinle Valley in northeastern Arizona at an elevation of less than 5000 feet.

The area in which the so-called glacial deposits occur is the home of the pyrope garnets or "Arizona rubies" exported from the Navajo Reservation, and a report by Sterrett on the production of precious stones in the United States calls attention to the unusual character of the material which overlies bed rock in the garnet fields.

"The drift is over 100 feet thick and is composed of bowlders which vary from stones weighing many tons to cobble size, mixed through a matrix of pebbles and sand. The gravel and bowlders consist of biotite granite gneiss, porphyritic biotite granite gneiss, hornblende or diorite gneiss, partly epidotized trap and basaltic rocks, epidote hornstone, soapstone, tremolite asbestos, sugary quartz, and large blocks of light gray colored fossiliferous limestone of Carboniferous age. Just where the origin of this conglomeration is to be sought is not known. The general appearance of the drift is that of a glacial deposit. Glaciation has taken place in the San Francisco Mountains of Coconino County, Arizona, and moraine deposits have been formed.[†] The latter are thought to be of rather recent age, probably Quaternary. Whether there has been glaciation in the slightly higher country

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[*] Dutton: Geology of the High Plateaus of Utah, 1880, p. 42.

[†] Atwood, W. W.: Glaciation of the San Francisco Mountains, Arizona, Jour. Geol., vol. xiii, pp. 276–279, 1905.

west and northwest of the garnet deposits is not known. It is probable that the garnet-bearing drift deposits are of greater age than the glacial deposits of the San Francisco Mountains, for the former are covered with a stratum of hard white sandstone, and are at almost as great an elevation as any of the surrounding region. The presence of such quantities of crystalline and ancient rocks in the drift cannot be explained by very recent action, as these rocks do not outcrop near the locality."*

The belief in the probable glacial origin of the gravels associated with the garnets of the Navajo Reservation was strengthened by the discovery of similar materials near the San Juan River at an elevation of 4800 feet. The deposits at this locality have been described by Woodruff.

"In the southeastern part of the [San Juan Oil] field there is a small area covered by debris which is believed to be of glacial origin. This material consists chiefly of fragments of sandstone, but includes also a considerable amount of shale and lesser amounts of interbedded limestone, conglomerate, and igneous rocks. The conglomerate is of two types—(1) well-rounded pebbles, in general similar to the Dakota conglomerate which is exposed to the northeast of the field, and (2) apparently metamorphosed conglomerate. Neither type resembles any of the other rocks exposed in this field. The igneous rocks comprise schist and gneiss. The deposit is a heterogeneous mass which shows no evidence of bedding, though some of the constituent blocks show traces of their original stratification. Fragments vary in size. One large block of conglomerate was found to be more than 100 feet in length. The mass rests in an old channel carved in the Moencopie and Dolores formations. The general trend of the channel is north and south, and it terminates at the south abruptly against a wall of shale and sandstone. Small garnets were found in the anthills on the top of the debris. These garnets are of interest in a study of the origin of the deposit, because similar ones were found scattered over the surface and in fragments of schist in the southeastern part of the field on the divide between Gypsum and Chin Lee creeks, where it is crossed by the wagon road. Sterrett suggested the glacial origin of garnet beds immediately south of the San Juan field, where rocks similar to the igneous rocks in this field are scattered over the surface."†

Granting that the deposits mentioned are glacial, the interest of the problem presented by the interpretations of Sterrett and of Woodruff is two-fold:

1. If the glaciation be assigned to Pleistocene times, these discoveries are remarkable in several respects. In the first place, a new record for the lower limit of the ice cap south of

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* Sterrett, D. B., Min. Res. U. S., for 1908, Pt. II, p. 825.

† Woodruff, E. F.: Geology of the San Juan Oil Field, Utah, U. S. Geol. Survey, Bull. 471, pp. 85–86, 1912.

latitude 40° is established, viz.: 4800 feet. Again the effect of climatic conditions producing glaciation must have been peculiarly localized along the Arizona–Utah boundary. The nearest known glacial materials are in the La Plata Mountains, about 100 miles to the northeast at an elevation of 8500 to 8800 feet and at San Francisco Mountain, 160 miles to the southwest where the terminal moraine of a glacier two miles in length rests at an elevation of 9200 feet. Carrizo Mountain, 40 miles east of the garnet fields, and 4620 feet higher in elevation, and Skeleton Mesa, 35 miles west and about 3000 feet higher, are without evidences of glaciation. Moreover the association of materials composing the drift of the garnet fields is unlike that reported elsewhere from Arizona, Colorado, New Mexico, or Utah.

(2) The statement of Sterrett, that "the garnet-bearing drift deposits . . . are covered with a stratum of hard white sandstone,"* points to a pre-Quaternary period of glaciation not elsewhere recognized in Arizona or Utah.

The erratics on the border of the glaciated (?) areas described by Sterrett and Woodruff were noted by the writer in 1910. In 1913 the outer edge of the "drift" at Garnet Ridge was mapped with the assistance of Mr. K. C. Heald, but the scarcity of water and the demands of the work in hand permitted no more than a superficial examination. During the past season a desire to examine the geologic features of the lower Chinle Valley and to study the problem presented by the glacial (?) deposits was realized in consequence of a grant from the Dana Research Fund of Yale University.

Geography.

Three areas covered by erratics have been located, one south and two north of the Arizona–Utah boundary line in longitude 109° 45′ (see map, fig. 1). The southernmost field has a superficial extent of about 1·2 square miles, but the erratics are dominant only in a belt one-half mile long and one-fourth mile wide at the eastern end of Garnet Ridge,† and on the other hand isolated bowlders are to be found beyond the limits of the area mapped. The Mule Ear field contains about ·25 square mile, in which bowlders are most abundant on the high ridge forming the west wall of Mule Ear Pass. The erratics of the Moses Rock field are strewn along a narrow, irregular belt six miles in length. The commanding topographic feature of the region is "the Comb," a cuesta which forms the eastern boundary of Monument Valley. The face of the cuesta is a wall of massive

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* Loc. cit., p. 825.

† The topographic and geologic terms appearing in this article are those adopted for use in forthcoming reports on the Geography and the Geology of the Navajo Reservation.

Fig. 1.

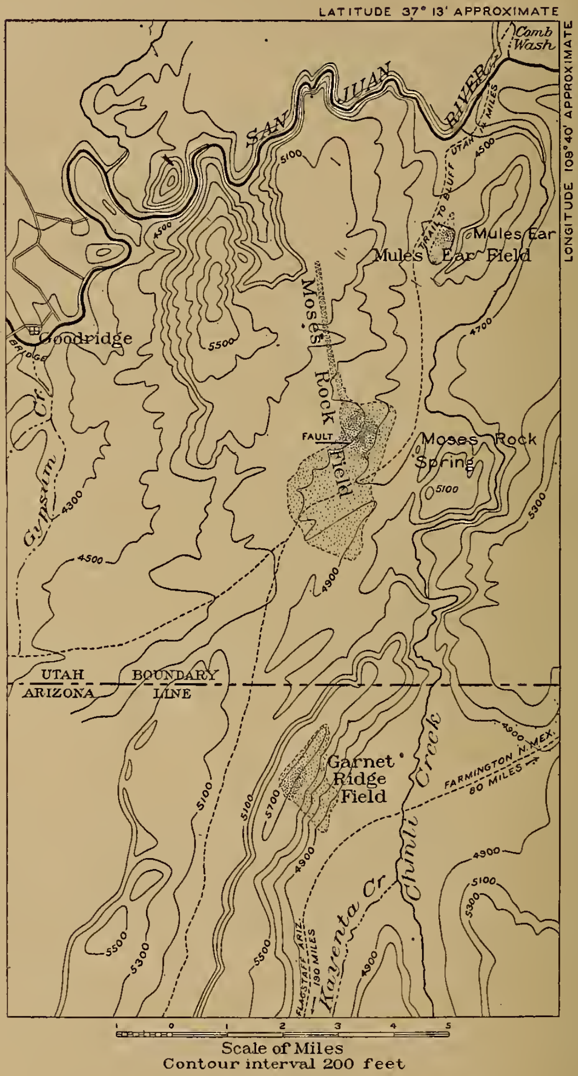

Fig. 1. Map of a portion of northern Arizona and southern Utah, showing the location of fields of erratic bowlders. Base compiled mainly from reconnaissance topographic sheets of the United States Geological Survey, and from Map of the San Juan Oil Field by E. G. Woodruff. The dissected ridge extending southward through Mules Ear, Moses Rock and Garnet Ridge is the Comb Monocline; Monument Valley extends westward beyond Gypsum Creek. Since the preparation of this map the spelling of Chinli has been changed by official action to Chinle and of Kayenta to Tyende.

red rock rising 300 to 500 feet above the valley at its western base and presenting slopes exceeding 60 degrees. The ridge is unbroken except where trenched by the rock-walled canyon of the Chinle, and its crest is set with red sandstone teeth culminating in a massive projection locally known as Mule Ear. West of this primary cuesta are a series of hogbacks in parallel position formed of the upturned edges of eastward-dipping sandstone strata.

The surface of the entire area is trenched by closely-spaced, deep-cut canyons with perpendicular walls; and innumerable mesas and buttes occupy the inter-canyon spaces. South of Mule Ear Pass the water channels are tributary to the Chinle, either directly down the back slope of the Comb Monocline or by devious routes among the ridges to the west. Drainage north of Mule Ear enters the San Juan, the master stream of the northeastern portion of the Navajo Reservation. The Chinle canyon is deeply filled with alluvium into which an inner canyon 10–30 feet deep has been cut; elsewhere a mantle of soil is lacking except for inconspicuous patches of recently disintegrated rock and piles of scattered dunes. Vegetation is therefore scanty except for isolated tufts of grass and hardy weeds which spring up rapidly following showers. Greasewood and yucca in widely-spaced groups are dominant in the lower lands; on the crest of the Comb, sage, piñon and cedar are able to maintain themselves.

The absence of soil, the steep gradients of the canyons, the scant annual precipitation which is made up of sudden short-lived showers, and the high values of rock absorption and of evaporation give to the water courses in this region their typical desert character, viz.: well-formed channels admirably adapted for carrying water but functioning only for a few hours at a time.

The fields of erratics may be reached from stations on the Denver and Rio Grande Railway at distances estimated as follows: Farmington, N. M., 80 miles; Dolores, Colorado, 110 miles; Thompson Springs, Utah, 160 miles. From the south a passable road, about 190 miles long, extends from Flagstaff, Arizona, via Tuba and Kayenta. From Gallup, N. M., the field may be reached, via Fort Defiance and Chinle, by a traverse of approximately 120 miles. The scarcity of water and of feed for stock, rather than distance, are the significant factors of travel in this region. The Moses Rock and Mule Ear fields may be studied with Moses Rock Spring as a base; in the vicinity of Garnet Ridge no water is available except that remaining in rock pockets for a few days following heavy rains. Saddle horse, pack train and a competent guide are essential accompaniments of detailed work.

General Geologic Relations.

The members of the stratigraphic column represented in the area under discussion embrace the following: the Goodridge formation (Pennsylvanian); the Moenkopi formation and the De Chelly sandstone (Permian); the Shinarump Conglomerate (Upper Triassic); the Chinle formation (Upper Triassic); the La Plata Group (Jurassic); and the McElmo formation (Jurassic or Lower Cretaceous). The Cretaceous strata outcropping at Carrizo Mountain and the Tertiary sediments of the Boundary Mountains to the east, which doubtless formerly extended over southern Utah and northeastern Arizona, are not present in the Chinle Valley. The deposits of erratic bowlders are associated with all the formations represented. In the Mule Ear area they are found upon and within the Moenkopi, the De Chelly, and the Chinle formations; in the Moses Rock field they occur upon and within the Moenkopi and rarely overlie Goodridge strata. At Garnet Ridge the Navajo sandstone, the upper member of the La Plata Group, is dotted here and there with igneous erratics; portions of the McElmo floor are thickly strewn with bowlders, and beds and lenses of "glacial conglomerate" are incorporated within the McElmo sediments.

Structurally the area under discussion is part of the Monument uplift, the eastern border of which is outlined by the Comb Monocline. In the Moses Rock field the Moenkopi strata dip eastward at angles of 4 to 20 degrees; at Mule Ear the beds are upturned at angles exceeding 50°; Garnet Ridge, on the back slope of the monocline, is composed of sedimentary beds whose eastward dip averages between 2° and 3°. A fault with slight displacement traverses the Moses Rock field, as noted by Woodruff, and minor displacements of strata at Mule Ear and Garnet Ridge, accompanied by landslides, have resulted in producing masses of jumbled rocks in greatly confused arrangement.

DESCRIPTION OF THE "GLACIATED" AREAS.

The Mule Ear Field.

As mapped by Woodruff, the "glacial" deposits at Mule Ear Pass cover an area of about one-fourth of a square mile and rest "in an old channel carved in the Moencopie and Dolores formations."* Approaching this field from the south, attention is attracted to the high ridge forming the west wall of the pass, and trending parallel with the dominating cuesta of Comb Monocline (fig. 2). Throughout its course, for many miles, this ridge is formed by upturned edges of massive De

* Bull. 471, p. 86.

Chelly sandstone and Shinarump conglomerate in relations normal to the Navajo Reservation. At the pass, however, the usual wavy and serrate crest of the ridge disappears and its place is taken by a disorderly array of massive blocks of sandstone and limestone; red or buff in general color, but in places painted black by a thick coat of desert varnish. Except for a distance of about one-fourth of a mile the sedimentary series is undisturbed; the underlying Moenkopi is followed in regular ascending order by De Chelly sandstone, Shinarump Conglomerate, Chinle shales and the three members of the La Plata Group. In ascending the ridge it is found that erratics are thickly strewn over the slopes and extend into the valley carved from the soft Chinle shales. Fragments and bowlders of granite, granite gneiss, garnetiferous diorite, slates, phyllites, schists and fossiliferous limestone are represented by numerous individuals. On the crest of the widened ridge and along its upper flanks bowlders and blocks of these materials are found in abundance. One granite bowlder three feet in diameter

FIG. 2.

FIG. 2. Mule Ear Pass viewed from the south. The rock in the left foreground is De Chelly sandstone and Shinarump Conglomerate; the valley is cut in Chinle shales; the massive rock walls in the right half of the picture, including the two points of Mule Ear, are formed of La Plata sandstone. The erratics cover the broken ridge in the extreme upper left-hand corner of the view.

was noted and angular blocks of Carboniferous limestone 20 to 100 feet in long diameter are not uncommon. This accumulation of igneous and metamorphic rock appears strangely out of place since no materials of these types are found *in situ* within the limits of the Navajo Reservation or beyond its borders for a distance of 100 miles from Mule Ear.

Among the materials capping the ridge masses of conglomerate, consisting of the materials represented in the "drift," were noted, and where outcrops are favorably displayed lenses and stringers of this conglomerate appear wedged between the blocks and tightly plastered against limestone and sandstone fragments. At the immediate contact between the conglomerate and the sedimentary rock, the limestone is in places discolored and partially crystallized and the sandstone is baked or even altered to a vitreous quartzite. In the jumbled mass it was found impracticable, with the time at our disposal, to map the scattered outcrops or to determine their inter-relations. Across the top of the ridge dark green bands of decomposed rock were noted, which on examination proved to be composed of fragments of igneous, metamorphic, and sedimentary rock set in a groundmass of finer materials. These bands, 2 to 6 feet wide, intersect the strata at various angles, have distinct borders, and are sharply differentiated from other portions of the terrane by their color. At no point was the material composing these streaks consolidated at the surface or in the two-foot trenches dug to determine their character. On the east side of the ridge one of these bands, traversing the strata in a vertical direction, was found to consist of fragments of granite, gneiss, schist, quartzite, and limestone held together by a paste of basic igneous fragments.

It will be seen from the above description that the conglomerate is intrusive in origin and that the green bands intersecting the upturned Mesozoic sediments are dikes of somewhat unusual aspect. The material exposed is rather a heterogeneous mass of sedimentary fragments intersected by stringers and lenses of conglomerate and paste rather than an igneous intrusion carrying inclusions of foreign rock. The number of dikes and their mutual relations was not determined, but the field relations suggest a plexus of contemporaneous dikes associated in a general intrusion. It is possible that the intrusion partakes of the nature of a volcanic neck or pipe, and that blocks of deep-seated rock were carried upward along a poorly-defined vent. The fact that some of the bowlders of limestone are of greater diameter than the width of any of the dikes observed is in harmony with this assumption.

All the erratics of the Mule Ear field may be accounted for on the assumption of igneous intrusion. The blocks of limestone carrying *Productus cora*, *Spirifer rocky montanus*, *Pugnax Utah*, and other characteristic Pennsylvanian fossils are identical with the strata of the Goodridge formation found in the San Juan Canyon, at a stratigraphic horizon several hundred feet lower than their position at Mule Ear. The igneous and metamorphic fragments are from a much greater depth.

The Moses Rock Field.

One of the sources of the "Arizona rubies" (pyrope garnets), offered to traders by the Navajo Indians, is a broken line of rounded knobs about two miles west of Moses Rock, Utah, In this region,—an area which has a north-south extension of about six miles and a width varying from less than five feet to one and one-half miles,—the bed rock is mantled by drift made up of fragments of granite, basic igneous rocks, a variety of gneisses, schists, and slates, and blocks of limestone and sandstone. On the west the field has a somewhat definite border; on the east the erratics are distributed along the water courses or in mesas and ridges and mounds in an apparently capricious manner. In the canyons northwest of Moses Rock the erratics, at first sparingly distributed on the dry valley floors or displayed on intercanyon mesas, increase in abundance westward to the crest of the ridge whose rounded and broken summit is buried in gravels, cobbles and bowlders, and square blocks from one inch to three feet in diameter. On the extreme summit of the ridge blocks of limestone 10 to 20 feet in width are mingled with the finer materials. A reconnaissance of the field indicated that the erratics were concentrated along a narrow irregular band with an average north-south trend and that the bowlders strewn over the eastern portion of the field owe their position to the storm water torrents which add their floods to the Chinle. The "drift"-covered belt consists of three distinct portions:

1. The northern portion, two miles in length, is a band 2–5 feet in width, consisting of an agglomerate of buff limestone and sandstone containing Pennsylvanian fossils. Included within this mass are fragments of red shale, sandstone, quartzite. minette, granite, and gneiss. Viewed from a distance this belt appears as a yellow-green streak crossing canyon and flat and ridge, sharply outlined against the dark red sandstone and shales of the Moenkopi formation. Its trend is N. 10° W., but numerous offsets of 10–50 feet give to the line a zigzag form. This conglomerate band is even with the surface throughout most of its extent, but on canyon walls it is replaced by a trench and at a few places it stands above the surface as the core of small mesas. The band clearly cuts the

country rock as a dike, and although no consolidated material was found either at the surface or by digging shallow trenches, the intrusive origin of the material is scarcely a matter of doubt. It differs from other dikes of the region only in the fact that the igneous paste constitutes probably less than five per cent of the mass. It is essentially a pudding of sedimentary fragments holding igneous plums.

2. The largest accumulation of erratics occurs at a point about two miles northwest of Moses Rock. At this locality the dike-like band is replaced by mounds of broken strata deeply covered with erratics and occupying an area about 1000 feet long and 500 feet wide. Four hills, highly irregular in outline and arranged along a north-south axis, rise 100–200 feet above the surrounding surface and are capped by chunks of limestone and sandstone 10 × 30 × 6 feet to 2 × 2 × 4 feet, arranged at various angles. Within this area both native and foreign rocks are piled in confusion, while on and among them are found the erratic gravels including fragments of rock of various types. All about this area of jumbled blocks the Moenkopi strata are undisturbed, displaying their normal easterly dip. With the drift-covered knolls the N. 10° W. direction of the belt of erratics abruptly ceases and the band of irregular mounds and ridges made of broken strata tilted at various angles extends westward for about one-half mile. This second portion of the erratic belt is believed to have the same origin as the narrow band at the north, from which it differs mainly in width and in quantity and variety of foreign material.

3. The southernmost portion of the Moses Rock field extends southwest, south and southeast in a sweeping curve, nearly four miles in length. At the north end, and especially at the south end of this line, the erratics form a belt of low knobs, in places merging into the sand-covered plain. For a distance of bout one mile the drift forms a ridge which stands 20 to 40 feet above the country at its base,—a ridge coated with ash-grey to green-grey gravels, contrasting strongly with the dark red Moenkopi strata upon which it appears to be resting. The strata both east and west of the grey-green ridge are seemingly in undisturbed position. The materials forming the crest of the ridge and strewn over its flanks include many of the erratics elsewhere noted in the Moses Rock area. Numerous fragments of chert and chalcedony are present and there is a large amount of mica-diabase or minette. Like other parts of the Moses Rock belt, this southern portion is thought to be located along a dike and the ridge is believed to owe its presence to remnants of the country rock made resistant by local metamorphism. The presence of fragments of diabase or minette, in places constituting 15 per cent of the debris, suggests

that this intrusion is similar in composition to that of the dikes and necks of Monument Valley 20 to 50 miles to the west.

Along the axis of the Moses Rock field the Moenkopi strata are faulted as indicated by Woodruff.* The amount of displacement is difficult to determine because of the absence of distinctive beds within the 500 or 600 feet of strata exposed. At the north end of the field the downthrow on the east appears to be less than ten feet; further south the displacement is somewhat greater but probably does not exceed 200 feet, the maximum assigned by Woodruff, and may be considerably less.

North of Moses Rock terraces along the Chinle and its western tributaries are heavily floored with gravel consisting of monzonite, quartzite, and sandstone. These materials find their origin in the Carrizo Mountains, about fifty miles distant, as measured along the streams, and are unrelated to the "drift" under discussion, from which they differ both in composition and origin. The erratics of the Moses Rock field are believed to have no connection with Pleistocene or Mesozoic glaciation, but to owe their origin to a dike or possibly a group of dikes intruded into Pennsylvanian and Permian strata.

THE GARNET RIDGE FIELD.

Character of the "drift."—In the lower reaches of the Chinle Valley the Navajo sandstone is laid bare over wide areas along the eastern limb of the Comb Monocline. At one locality about three miles south of the Utah line overlying strata remain in the form of a terraced ridge which terminates in a series of rounded buttes. This area is the principal source of the Arizona garnets of commerce.† The remarkable feature of the district is the presence of fields of bowlders, hills capped by gravel of an unusual aspect, and beds and lenses of conglomerate of a character not observed elsewhere. This erratic conglomerate covers the east end of Garnet Ridge, forms a talus on its south and west flanks, mantles the adjoining buttes, and forms a thin disconnected cover of the wind-swept Navajo sandstone extending from Garnet Ridge southward toward Tyende Creek and eastward nearly to the Chinle. The bowlders are most numerous on top of the ridge and buttes and along their southern slopes and upon the bare rock floor at their bases. At one point forty bowlders exceeding two feet in diameter are in view and smaller erratics may be counted

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*Loc. cit., pp. 88–89.

† Sterrett, loc. cit.

Gregory, H. E.: Garnet Deposits of the Navajo Reservation, to be published in Economic Geology.

FIG. 3.

FIG. 3. View of a part of the Garnet Ridge Field, showing distribution and size of bowlders. Note the saddle horse standing among the bowlders.

FIG. 4.

FIG. 4. Bowlders of granite, granite gneiss, limestone, and sandstone, Garnet Ridge.

by hundreds. Two bowlders of porphyritic granite, 14 × 8 feet and 5 × 3 feet respectively, stand isolated on the dune-covered flat fully a mile from their nearest companions. The field entirely or in part mantled by these materials is about 1·2 square miles, but individual fragments are much more widely scattered. The size and mode of distribution of these erratics are illustrated in figures 3, 4 and 5.

Specimens collected from the drift include the following: sandstone, shale, limestone, biotite granite, garnetiferous diorite, diabase (?), minette, granite gneiss, porphyritic granite gneiss, garnetiferous diorite gneiss, muscovite schist, chlorite schist, slate, hornstone, quartzite, garnet, peridot, lustrous feldspar, quartz, chalcedony, augite, diopside, epidote, soapstone, tremolite, asbestos. None of the igneous and metamorphic rocks included in the list are found in place within 100 miles of this area, and the nearest outcrop of Pennsylvanian limestone occurs in the bed of the San Juan river 20 miles north. It thus appears that this deposit is local and that its position and character are peculiar.

Fig. 5.

Fig. 5. Granite bowlders, Garnet Ridge.

Features suggesting glaciation.—The photographs (figs. 3 and 6) bear out the statement of Sterrett, "The general appearance of the drift is that of a glacial deposit." In fact several features ordinarily relied upon to establish the glacial origin of surface deposits are present at Garnet Ridge. The debris is accumulated in mounds or spread unevenly over the surface. It rests in places directly upon the smoothed surface of bed rock, and fragments of country rock are found in abundance among the pebbles. The deposit is heterogeneous; fragments of various materials, in sizes from that of the constituents of rock flour to bowlders several feet in diameter, are confusedly intermingled; and several of the larger bowlders are perched in an insecure position. The constituents of the drift are of a variety of shapes; subangular specimens are most abundant; some are rounded, many are angular. Cobbles with smoothed faces and angular edges, also soled and snubbed and polished fragments, are not uncommon, and a few striated pebbles were seen. The conglomerate interbedded with Jurassic (?) strata is identical in texture and composition with the surficial drift. If the form and arrangement of pebbles be emphasized, the materials described may properly be classed

Fig. 6.

Fig. 6. General view of a portion of the "glacial field," Garnet Ridge. Eighteen varieties of rock fragments were collected within the area shown.

with tillites, but as suggested elsewhere[*] the shape of pebbles is of little significance especially in small outcrops.

Disregarding the possibility of an igneous origin of the peculiar conglomerate interbedded with the sediments, the assumption of glaciation during Mesozoic time is directly opposed to the physiographic evidence. The color, composition, texture and structure of the sediments indicate a warm, arid climate, and uninterrupted sedimentation. Under such conditions the presence of vigorous glaciers is not to be expected. It is believed by the writer that the demonstration of suitable climatic conditions is an essential feature in the recognition of ancient glacial deposits.

Position of the "glacial" conglomerate in the stratigraphic column.—After confirming the observation of Sterrett that the "glacial" materials not only covered the surface, but were also interstratified with undisturbed sandstones and shales, a section of Garnet Ridge was measured as follows:

Section of Garnet Ridge, Arizona.

Taken on N. 40° W. line   Dip of strata, 40° E. ∠ 3°

		Feet
1.	Sandstone, grey to white; fine, uniform grain, except for millet seed grains cemented on bedding planes and cross-bedding laminae; ripple marks and mud cracks present. Grains of clear, round quartz, white with rare red and black individuals, poorly cemented, cross-bedded at low angles rarely tangential. Intersected by seams of calcareous sand 1/100–2 inches in width. Prominent joints N. 40° E. and N. 40° W.	25
2.	Arenaceous and calcareous shales and sandstone. Light red, dark red and brown in alternating bands, 1 to 3 feet in thickness. Cross-bedding poorly defined, but bedding planes irregular and wavy and rock traversed by undulating streaks and minute faults and folds	30
3.	Sandstone, grey, white and variegated; calcareous, friable, irregularly bedded, imbricated and cross bedded	10
4.	Shales, arenaceous and argillaceous, with variable amounts of sandstone; dark red, light red, green-white, ash grey or variegated in color. Within a few feet along strike shale in places replaced by lenses of calcareous sandstone built of overlapping short laminae	15
5.	Sandstone, light red, white on fresh fracture; calcareous, irregularly bedded, ripple marked	2

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[*] Gregory: Note on the Shape of Pebbles, this Journal, xxxix, pp. 300–304, 1915.

	Feet
6. Shales, argillaceous, calcareous, arenaceous, with 2–14 inch beds and lenses of white and of light red sandstone; shales various tones of red and brown, also ash grey and green	35
7. *Conglomerate, olive-green in tone, compact, but not firmly cemented. The pebbles in sizes up to 16 inches in long diameter are subangular with flattened and in many cases polished surfaces, and include white granite, granite porphyry, granite gneiss, diorite, garnetiferous diorite gneiss, mica schist, chlorite schist, serpentine, asbestos, quartzite, blue-grey marble, grey and buff limestone, red sandstone, red shale; the matrix consists of tiny particles of rock types present as pebbles, and also flakes of biotite and muscovite, rare garnets and peridots. Materials of the conglomerate identical except in size with those forming the surface "drift" of this area. The upper and lower contacts of the conglomerate somewhat wavy and shales enclosing it are slightly discolored. Bed traced by excavation for 200 feet, terminates abruptly at the west*	4
8. Sandstone, fine, even-grained, light red, lenticular; replaced along the strike by white, sandy shales	1
9. Shale, arenaceous; banded white, green, ash gray, dark red, light red, chocolate; colored bands in places continuous for several hundred feet; elsewhere distributed as discontinuous stripes or as dots; beds paper-thin to ⅛ inch in thickness; uneven, wavy, and in places imbricated	42
10. Sandstone, red-brown, fine; well-rounded, quartz grains; calcareous cement	5
11. Shale, arenaceous; dark red to light brown, with scattering patches of black, white and green; irregularly bedded; where shale partings are not developed by weathering, strata assume appearance of thick bedded, variegated sandstone	28
12. Sandstone, dark red with white patches; many curved beds; massive or irregularly bedded; friable; fine quartz, even-grained; weathers into knobs, hoodoos, stone babies, bobbins	30 ±
	227
13. Sandstone, light red, massive, cross-bedded; Navajo sandstone, the upper member of the La Plata Group.	

The strata included in this section, Nos. 1–12, inclusive, are tentatively assigned to the McElmo formation, Jurassic (?) in age.

A section of the southwest end of Garnet Ridge, measured with the assistance of Mr. Heald, is substantially the equivalent of the one given above, except that No. 7 is not represented.

As shown in the diagram (fig. 8), the conglomerate bed (No. 7) could be traced for less than 300 feet, but material identical in character, in an uneven stratum 2 to 8 feet in thickness (fig. 7), is found about 500 feet farther east beneath the cap of white sandstone (No. 1 of the section), and a bed of the same composition occurs near the top of a detached butte near at hand. On following the conglomerate bed by excavations, it was found to turn abruptly upward, and after an offset of 20 feet to extend to the top of the ridge. To the north of the ridge the bed was again found on the floor of a natural ditch. Further examination led to the conclusion that the stratum of conglomerate in both vertical and horizontal position is of igneous origin—a dike and sheet of abnormal composition.

FIG. 7.

FIG. 7. East end of Garnet Ridge. The man in the figure is standing on the stratum of "glacial" conglomerate.

Microscopic examination of the bed furnished corroborative testimony.

The stratification of Garnet Ridge is undisturbed except for a distance of about 400 feet, within which the sediments are broken into blocks tilted at various angles and rendered more

Fig. 8. Diagrammatic section of east end of Garnet Ridge, showing the position of the interbedded stratum of conglomerate, A, of the area of disturbed strata, B, and of the bowlders strewn over the surface. The construction of the volcanic pipe is wholly theoretical. The numbers on the beds correspond with those described in the section, pp. 111–112.

confused by sliding of block on block and of parts of the mass on the shales beneath. Within this tangled mass of blocks the conglomerate is distributed as chunks and lenses and stringers and surficial patches in a most capricious manner. It was found impracticable to determine the distribution and continuity of the various igneous and sedimentary beds involved in this complex, but it is believed that these disturbed beds mark the location of the principal intrusion. That the assumed intrusion is local, somewhat in the nature of a neck, is suggested by the fact that the beds near at hand, north, south and west of the disturbed area, are continuous and in their usual positions. It is possible, also, that a dike extends eastward through the heavily-mantled knolls and buttes, but no definite trace of it was discovered.

The age of the intrusion is unknown beyond the fact that it is post-Jurassic, but the field evidence demands no date earlier than that assigned to the other volcanic features of the Navajo Reservation, viz: Tertiary time. As in the case of the Mule Ear and the Moses Rock localities, the igneous origin of conglomerate at Garnet Ridge appears to be demonstrated.

Corroborative evidence.—At a number of localities within the boundaries of the Navajo Reservation igneous intrusions in the form of dikes, sheets, laccoliths, and volcanic necks occur. Few of these exhibit the features ordinarily associated with igneous masses. Many of them are vertical sheets of consolidated agglomerate in which massive igneous rock plays a minor rôle. A few dikes and necks studied consist of over 75 per cent of conglomerate, in which fragments of sedimentary rock exceed in bulk the broken bits of minette, shonkinite, and augitite. The most common foreign ingredients are blocks of sandstone and shale through which the igneous material has made its way, but bits of igneous, metamorphic and sedimentary rocks from unknown deep sources are also in evidence. At Alhambra Dike, granites and gneisses are embedded in the augite minette. Plastered against the diabase of Church Rock two varieties of granite gneiss and fragments of chlorite schist, quartzite, chalcedony and augitite were found. Within one of the dikes cutting Comb Monocline garnetiferous gneiss, granite, slate and limestone are found among the inclusions. The igneous masses within Buell's Park hold inclusions of hornblende, gneiss, garnetiferous diorite gneiss, marble, slate, mica schist, and chert. It is probable that careful search for inclusions within the igneous masses of the Reservation would result in a collection containing nearly all the varieties of pebbles found in the "drift" of the garnet fields.

Conclusion.

Materials resembling glacial deposits on the Navajo Reservation occur as strata interbedded with Mesozoic sediments and also as superficial drift. Their position in the stratigraphic column is believed to be due to igneous agencies; their distribution over the present surface the result of erosion rather than of Pleistocene glaciation. Most of the bowlders are assigned to pre-Cambrian formations. Whether the "glaciated" forms of the pebbles have resulted from compression in ancient conglomerates, from a pre-Cambrian period of glacia tion or directly from igneous activity, has not been determined.

ART. IX.—*The Energy of a Moving Electron*; by LEIGH PAGE.

IN a previous paper* it has been shown that the equations of the electromagnetic field can be derived in their entirety from two fundamental assumptions, to wit:

(*a*) An ether exists which transmits strains in accordance with the postulate of the relativity of all systems moving with constant velocities;

(*b*) The elementary charge is a center of discrete, uniformly diverging, tubes of strain.

The object of the present paper is to discuss and compare the expressions for the energy of a Lorentz electron moving with constant velocity as obtained by three distinct methods. The first of these methods consists in finding the electric and magnetic energies of the electron's field. The second consists in subjecting an electron which is at rest relative to the observer to an infinitesimal mechanical force for an infinite time. In this way a finite velocity is imparted to the electron without any finite radiation of energy. Hence the sum of the initial electrostatic energy of the electron, the work done by the mechanical force in accelerating the electron, and the work done by the ether pressure,—or whatever other force is postulated in order to prevent the disruption of the electron,—in producing the progressive contraction of the electron as its velocity relative to the observer increases, gives the energy of the moving electron. The third method is analogous to that used in finding the electrostatic energy of a charged conductor. Starting with an uncharged moving electron, an infinite number of shells of infinite radius are shrunk down to the surface of the electron. Each shell carries an infinitesimal charge and maintains throughout the process of contraction the same velocity as the electron. The sum of the work done in contracting the shells and that done in maintaining their constant velocity against the retardation of the field gives the energy of the charged electron.

The value of the total energy is, as it must be, independent of the method used. The division into kinetic and potential energies is, however, not the same for the different methods. In the first method the kinetic energy is taken as the magnetic energy of the moving electron's field. The second method gives for the kinetic energy the work done by the accelerating force. This is the expression peculiar to the dynamics of relativity, and does not agree with that obtained by the first

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* This Jour., xxxviii, p. 169, 1914.

method. In the third method the kinetic energy is measured by the work done in maintaining unimpaired the velocity of the contracting shells. Its value is equal to that of the magnetic energy of the moving electron's field as given by the first method. Of the three methods the second would appear to be the least trustworthy on account of the necessity of dealing with an accelerated system.

If the elementary charge or electron is a uniformly charged spherical shell of radius a to an observer relative to whom it is at rest, it will appear as an oblate spheroid to an observer relative to whom it has a constant velocity v, the dimensions at right angles to the direction of motion being the same as when at rest, and the dimensions in the direction of motion being shortened in the ratio $\sqrt{1-\beta^2} : 1$ where $c = \frac{v}{\beta} =$ velocity of light. If a mechanical force be applied to such an electron, the electron's own field will exert a force opposite and proportional to the acceleration produced. By means of this retarding force Lorentz* explains the inertia mass of a moving electron. For a quasi-stationary state of motion he finds the transverse mass to be given by

$$m_t = \frac{e^2}{6\pi ac^2\sqrt{1-\beta^2}} = \frac{m_0}{\sqrt{1-\beta^2}} \qquad (1)$$

and the longitudinal mass by

$$m_l = \frac{e^2}{6\pi ac^2\,(1-\beta^2)^{\frac{3}{2}}} = \frac{m_0}{(1-\beta^2)^{\frac{3}{2}}} \qquad (2)$$

If the acceleration is finite and in the direction of relative velocity, it must be remembered that the acceleration of the front of the electron is less than that of the rear, since the electron contracts progressively as its velocity relative to the observer increases. The author has shown, in the paper already referred to, that Lorentz's expressions for the mass hold good for any acceleration which is constant relative to the electron's own system, provided we take as the acceleration of the electron, not the acceleration of its geometric center, but that of the plane perpendicular to the direction of motion, which divides the electron into two parts having equal charges. The point where the axis of the electron cuts this plane may appropriately be called the center of acceleration. The restriction of constant acceleration relative to the electron's own system is not serious, since a constant acceleration for a time comparable to that taken by light to travel a distance equal to

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* Theory of Electrons, p. 212.

the diameter of the electron is all that is necessary in order that the expressions given above shall hold. While the expression for the longitudinal mass has not been verified experimentally, that for the transverse mass has been found to hold very exactly for high speed β particles, first by Kaufmann* and Bucherer,† and more recently to a high degree of precision by G. Neumann.‡

First Method.

To calculate the energy of a moving electron by the customary method use is made of the familiar energy equation which follows at once from the equations of the electro-magnetic field and the transformation equation for the force. If vectors be denoted by **Gothic** letters, the force equation, in Gibbs' notation, has the form

$$\mathbf{F}=\rho\left[\mathbf{E}+\frac{1}{c}\mathbf{v}\times\mathbf{H}\right] \tag{3}$$

where $\mathbf{F}$ denotes the force per unit volume, due to the electric strain $\mathbf{E}$ and the magnetic strain $\mathbf{H}$, on a charge of density ρ moving with velocity $\mathbf{v}$. The energy equation is

$$\frac{d}{dt}\left[\frac{1}{2}\int(E^2+H^2)\,d\tau\right]+c\int(\mathbf{E}\times\mathbf{H})\cdot d\mathbf{s}+\int\mathbf{F}\cdot\mathbf{v}\,d\tau=0 \tag{4}$$

The first term represents the rate of increase in the energy of the electron's field, the second term the rate of radiation, and the third the rate at which work is done on the electron by its own field. The first term gives for the potential energy of the moving electron's field

$$U_1=\frac{1}{2}\int E^2\,d\tau=\frac{e^2}{24\pi a}\,\frac{3-\beta^2}{\sqrt{1-\beta^2}}=\frac{m_0c^2}{4}\,\frac{3-\beta^2}{\sqrt{1-\beta^2}} \tag{5}$$

and for the kinetic energy

$$T_1=\frac{1}{2}\int H^2 d\tau=\frac{e^2}{12\pi a}\,\frac{\beta^2}{\sqrt{1-\beta^2}}=\frac{m_0c^2}{2}\,\frac{\beta^2}{\sqrt{1-\beta^2}} \tag{6}$$

Hence the total energy of the moving electron is

$$W=\frac{e^2}{24\pi a}\,\frac{3+\beta^2}{\sqrt{1-\beta^2}}=m_0c^2\left[\frac{1}{\sqrt{1-\beta^2}}-\frac{1}{4}\sqrt{1-\beta^2}\right] \tag{7}$$

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* Kaufmann, Ann. d. Physik., xix, p. 487, 1906.
† Bucherer, Phys. Zeitschr., ix, p. 755, 1908.
‡ Neumann, Ann. d. Physik., xlv, p. 529, 1914.

and the gain in energy due to the motion, obtained by subtracting from (7) the electrostatic energy of an electron at rest relative to the observer, is given by

$$\Delta W = m_0 c^2 \left[\frac{1}{\sqrt{1-\beta^2}} - 1 \right] \left[1 + \frac{\sqrt{1-\beta^2}}{4} \right] \tag{8}$$

The rate of radiation of energy from an electron is given exactly by

$$\frac{dR}{dt} = \frac{e^2 \phi^2}{6\pi c^3} \tag{9}$$

where ϕ is the acceleration of the center of strain* of the electron relative to its own system.

Second Method.

Let an electron which is initially at rest relative to the observer be given a finite velocity v by imparting to it an infinitesimal acceleration for an infinite time, and then let the electron be allowed to maintain this velocity forever after. Since the acceleration is infinitesimal, the radiation term will be negligible compared to the other terms in (4). Hence we may write

$$\frac{d}{dt}\left[\frac{1}{2} \int (E^2 + H^2)\, d\tau \right] + \int \mathbf{F} \cdot \mathbf{v}\, d\tau = 0 \tag{10}$$

To find the gain in energy we must calculate the work done by the constant mechanical force which produces the acceleration. This force is obviously given by

$$K = -\int F_z\, d\tau = \frac{m_0 f}{(1-\beta^2)^{\frac{3}{2}}} \tag{11}$$

where the acceleration, since it is infinitesimal, can be considered to be the same for all points on the electron.

Integrating (11) we find for the work done by the mechanical force acting on the electron

$$T_2 = m_0\, c^2 \left[\frac{1}{\sqrt{1-\beta^2}} - 1 \right] \tag{12}$$

which is not the same as (8). In fact, if v_0 is the velocity of the geometric center, the work done by the mechanical force as calculated above is

$$T_2 = -\int \mathbf{v}_0\, dt \cdot \int \mathbf{F}\, d\tau$$

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* By "center of strain" is meant that point inside the electron at which its charge can be considered as concentrated without altering the external field.

whereas the change in energy as given by (8) is

$$\Delta W = \left[\frac{1}{2}\int(E^2+H^2)\,d\tau\right]_t - \left[\frac{1}{2}\int(E^2+H^2)d\tau\right]_0 = -\iint \mathbf{F}\cdot\mathbf{v}\,d\tau dt$$

which is not the same as T_2, because for the Lorentz electron

$$\int \mathbf{v}_0\,dt\cdot\int \mathbf{F}\,d\tau \neq \iint \mathbf{F}\cdot\mathbf{v}\,d\tau\,dt \tag{13}$$

This inequality means, physically, that in calculating the work done we cannot replace the forces acting on the elements of the electron by a single force acting at the center or at any other specified point in the electron. This is due, of course, to the fact that the electron is deformable and consequently when it is accelerated, different points on its surface have different velocities. In the case of a rigid electron (i. e., one which maintains the same size and shape whatever its velocity relative to the observer), such as Abraham's, the velocities of all points would be the same, and (13) would be an equality.

It is of interest to examine more closely the right-hand side of (13). If the origin be taken at the center of the electron, and the Z axis in the direction of relative velocity,

$$v = v_0\left[1 - \frac{z'\phi}{c^2}(1-\beta^2)\right] \tag{14}$$

where ϕ is the infinitesimal, constant acceleration of the electron relative to its own system, and primes refer to the electron's system at the instant considered.* Also

$$dF_z = \frac{e^2}{16\pi a^4}\left(1-4\frac{z'\phi}{c^2}\right)z'dz' \tag{15}$$

Multiplying (15) by v_0 and integrating over the surface of the electron we get

$$v_0\int dF_z = -\frac{m_0 f}{(1-\beta^2)^{\frac{3}{2}}}v_0 \tag{16}$$

for the rate at which work is done by the electromagnetic forces in resisting the change in motion. Changing the sign of this expression and integrating with respect to the time, we obtain the work done by the mechanical force producing the acceleration as given by (12).

Multiplying (15) by the second term in (14), we get upon integrating over the surface of the electron

$$-v_0(1-\beta^2)\int\frac{z'\phi}{c^2}\,dF_z = -\frac{m_0 f}{4\sqrt{1-\beta^2}}v_0 \tag{17}$$

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* See "Relativity and the Ether," this Journal, xxxviii, p. 169, 1914.

which is obviously the rate at which work is done by the electromagnetic forces in resisting the progressive contraction of the electron as its velocity increases. Changing signs and integrating with respect to the time, we get for the total work done in contracting the electron the expression

$$\triangle U_2 = \frac{m_0 c^2}{4}\left[1 - \sqrt{1-\beta^2}\right] \tag{18}$$

Adding this to (12), the expression for the work done by the mechanical force in producing the change in velocity, we get, as we should, for the total increase in energy the same expression (8) as obtained by subtracting the initial value of

$$\frac{1}{2}\int(E^2 + H^2)\,d\tau$$

from its final value. In accordance with the usual definitions we should consider (12) as representing the kinetic energy acquired, and (18) the increase in potential energy due to the contraction. It is to be noted, however, that the kinetic and potential energies so measured do *not* correspond to the magnetic and electric energies respectively of the electron's field.

In order to provide a mechanism for producing the contraction of the electron Poincaré* assumed that its surface is subject to a constant hydrostatic pressure

$$S = \frac{e^2}{32\pi^2 a^4} \tag{19}$$

This pressure is just sufficient, when the electron is moving with constant velocity, to counteract the electric forces tending to disrupt the electron, and when the acceleration is *infinitesimal*, the work done in contracting the electron against the electromagnetic forces due to its own field can be accounted for by the work done by this hydrostatic pressure. Unfortunately, however, Poincaré's stress loses its significance when an electron is accelerated by a finite mechanical force. If the force is constant, the electron's field will be such that if the surface of the electron is assumed to coincide with a level surface† of the electromagnetic field—and it is hard to see

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*Poincaré, Rendiconti del Circolo Matematico di Palermo, xxi, p. 129, 1906.

† By "level surface" is meant a surface everywhere perpendicular to the electromagnetic forces of the field. See "Relativity and the Ether." This Journal, xxxviii, p. 184, 1914. In the paper referred to, instead of "level surface" the term "equipotential surface" is used. The latter term is, however, objectionable, since the force in an accelerated system is not derivable from a scalar potential and hence there can be no meaning to "equipotential surface" in the sense of a surface all points of which have the same potential.

how the charge could be in equilibrium otherwise,—the distribution of electricity on the surface of the electron will not be uniform, and consequently the electric forces tending to disrupt the electron cannot be counteracted by a hydrostatic pressure. If the pressure is not hydrostatic, but of such a magnitude at each point on the surface as to balance the disruptive forces, it will exert a resultant force in the direction of motion that will exactly balance the retarding force due to the electron's own field, and in order to satisfy the equation of motion for the electron it would be necessary to introduce a mechanical mass. The most obvious way to avoid this difficulty is to deny the existence of mechanical forces *per se*, and put everything on an electrodynamic basis, at least in so far as the motion of electrons is concerned. Then in dealing with the motion of an accelerated electron we could not eliminate the external electromagnetic field which was responsible for the acceleration. We should have to deal with two overlapping fields, which would render the problem more complicated. So far as mechanical forces are concerned, it would seem that a body which is subject to a mechanical force must have a mechanical mass.

Third Method.

We will now calculate the energy of an electron moving with a constant and finite velocity v by a method analogous to that used in finding the electrostatic energy of a stationary charged conductor and without causing the electron to pass through a series of states in which the velocity varies.

To an observer relative to whom it is at rest, we have assumed the electron to be a uniformly charged spherical shell. Hence the kinematical transformations of relativity show that it will be an oblate spheroid to the observer relative to whom it has the constant velocity v. If the origin of moving axes is taken at the center of the electron with the Z axis parallel to the direction of motion, the surface of the electron will be that formed by revolving the ellipse

$$\frac{x^2}{a^2} + \frac{z^2}{a^2(1-\beta^2)} = 1 \tag{20}$$

about the Z axis. If θ is the angle made by any radius vector of the ellipse with the Z axis, the charge on the annular ring between the cones defined by θ and $\theta + d\theta$ is easily seen to be

$$de = \frac{e}{2}\frac{(1-\beta^2)\sin\theta d\theta}{(1-\beta^2\sin^2\theta)^{\frac{3}{2}}} \tag{21}$$

In order to find the energy of the moving electron we shall charge it by shrinking down from infinite size to its surface a series of moving shells. Each shell will carry an infinitesimal charge de distributed over its surface in such a way as to give rise to no field inside the shell, and will maintain throughout the process of contraction the same velocity as the electron. The work done in shrinking these shells against the forces exerted by the charge already on the electron will be equal to the energy of the electron in its final state.

First it is necessary to show that the energy of n shells of radius R and charge de, where R is infinitely great and $nde = e$ is finite, is negligible compared to that of an electron of charge e and finite radius a. A consideration of dimensions alone shows that the energy of one of these shells must be proportional to $\frac{(de)^2}{R}$ while that of the electron itself must be proportional to $\frac{e^2}{a}$. Hence the energy of the n shells will be proportional to $\frac{ede}{R}$ which is an infinitesimal of the second order compared to $\frac{e^2}{a}$. This must be true quite irrespective of the velocities of the shells and of the electron, provided these velocities are less than the velocity of light. Hence the energy of the n shells of infinite radius moving with velocity v is negligible compared to the work done in contracting them.

Moreover in contracting a shell, the work done against the electromagnetic forces due to the shell itself will be of the order $\frac{(de)^2}{r}$ and hence negligible compared to the work done against the forces due to that part of the charge which is already on the surface of the electron. So in calculating the energy we need consider only the work done against the forces exerted by the charge already on the electron's surface.

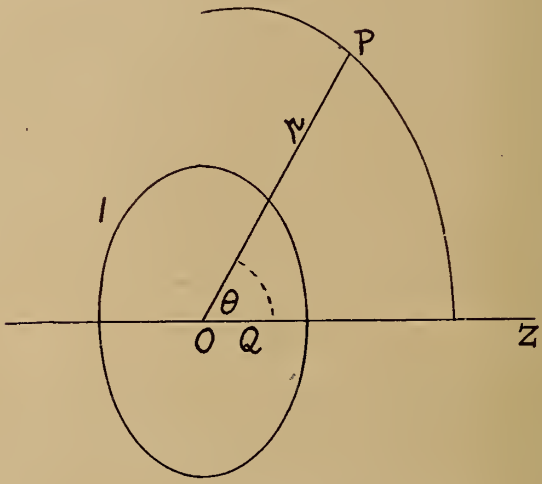
Let O (fig. 1) be the center of the electron and P a point on the contracting shell. The electric and magnetic forces at P are given by the familiar expressions

$$E = \frac{e}{4\pi r^2} \frac{(1-\beta^2)}{(1-\beta^2 \sin^2\theta)^{\frac{3}{2}}} \tag{22}$$

$$H = \frac{e}{4\pi r^2} \frac{\beta \sin\theta\ (1-\beta^2)}{(1-\beta^2 \sin^2\theta)^{\frac{3}{2}}} \tag{23}$$

In order that the contracting shell shall give rise to no field in its interior, it is obviously sufficient that relative to an observer moving with it the shell should be a uniformly charged sphere concentric with the electron. Let the infinitesimal radial velocity of contraction relative to such an observer be denoted by w' and the radius of the sphere by r'. Then the Lorentz-Einstein kinematical transformations show that, to an observer relative to whom the electron and shell have the velocity v, the shell will be an ellipsoid similar to the electron itself, but with its center displaced relative to that of the electron in the positive Z direction by an amount*

Fig. 1.



$$\overline{OQ} = r'\frac{w'}{c}\beta\sqrt{1-\beta^2} \tag{24}$$

Nevertheless, the charge on the annular ring between the cones defined by θ and $\theta + d\theta$ (θ being, as before, the angle between the radius vector drawn from the *center of the electron* and the Z axis) will bear the same ratio to the total charge on the shell as that on the corresponding ring of the electron's surface does to the total charge on the electron; in other words, the distribution of charge on the surface of the shell will be that given by (21). Consequently when the shell has contracted down to the surface of the electron and has imparted its charge to the same, no redistribution of electricity over the surface of the electron will be necessitated.

---

* If the shell were not contracting it would be concentric with the electron. The eccentricity of the contracting shell is due to the smaller velocity on the front, and greater velocity on the back of the shell.

From (3) we find for the rate at which work is done on the charge contained on an element of the surface of the contracting shell

$$\frac{dW}{dt} = -\,de\left[\mathbf{E}\cdot\mathbf{v}+\mathbf{E}\cdot\frac{d\mathbf{r}}{dt}\right] \tag{25}$$

Putting

$$W = U_3 + T_3$$

where

$$\frac{dU_3}{dt} = -\,de\,\mathbf{E}\cdot\frac{d\mathbf{r}}{dt} \tag{26}$$

and

$$\frac{dT_3}{dt} = -\,de\,\mathbf{E}\cdot\mathbf{v} \tag{27}$$

we find, on substituting from (21) and (22)

$$dU_3 = \frac{e\,de\,(1-\beta^2)^2}{8\pi}\int_0^{\pi}\int_b^{\infty}\frac{\sin\theta\,d\theta\,dr}{r^2\,(1-\beta^2\sin^2\theta)^3}$$

$$= \frac{e\,de}{12\pi a}\,\frac{3-\beta^2}{\sqrt{1-\beta^2}}\,, \tag{28}$$

$$\text{where } b = \frac{a\sqrt{1-\beta^2}}{\sqrt{1-\beta^2\sin^2\theta}}\,.$$

Integrating with respect to e to find the work done in shrinking all the shells down to the surface of the electron, we find for the total *potential energy*

$$U_3 = \frac{e^2}{24\pi a}\,\frac{3-\beta^2}{\sqrt{1-\beta^2}} = \frac{m_0c^2}{4}\,\frac{3-\beta^2}{\sqrt{1-\beta^2}} \tag{29}$$

which is the same as the *electric* energy of the electron's field, i. e.

$$U_1 = \frac{1}{2}\int E^2\,d\tau \tag{30}$$

Subtracting from U_3 the electrostatic energy of a charged conducting sphere, we find for the increase in potential energy due to the electron's motion

$$\Delta\,U_3 = \frac{m_0c^2}{4}\left[\frac{3-\beta^2}{\sqrt{1-\beta^2}}-3\right] \tag{31}$$

Equation (27) indicates that there is a resultant electric force on the contracting shell in such a direction as to oppose its motion. The mechanical force which must be applied to counteract this resistance is easily found to be

$$
\begin{aligned}
K_1 &= -\int E_z\, de \\
&= \frac{ede\, w'\, \beta}{6\pi r'^2 c} \\
&= -\frac{ede \dfrac{dr'}{dt}\, \beta}{6\pi r'^2 c\, \sqrt{1-\beta^2}}
\end{aligned}
\tag{32}
$$

since $dt' = dt\,\sqrt{1-\beta^2}$

The total work done by this force during the shrinking on of all the shells is seen to be

$$T_3 = \frac{e^2}{12\pi a}\,\frac{\beta^2}{\sqrt{1-\beta^2}} = \frac{m_0\, c^2}{2}\,\frac{\beta^2}{\sqrt{1-\beta^2}} \tag{33}$$

As this is the work done by the force applied to the shells in the direction of motion in maintaining their velocity unimpaired, it may properly be called the *kinetic energy* of the electron. It is equal in value to the *magnetic* energy of the electron's field, i. e.

$$T_1 = \frac{1}{2}\int H^2 d\tau \tag{34}$$

The sum of the potential and kinetic energies as determined above is, of course, equal to the corresponding total energy as measured by adding to the electrostatic energy of an electron at rest the work done in imparting to it, by means of an infinitesimal mechanical force, a velocity v. It is to be noted, however, that the division of the total energy into kinetic and potential is different in the two cases, as is seen by comparing (31) with (18), and (33) with (12). Denoting the transverse mass by m_t (33) gives for the kinetic energy the familiar expression

$$T_3 = \frac{1}{2}\, m_t v^2 \tag{35}$$

instead of the expression (12) peculiar to Einstein's mechanics.

It is of interest to investigate the validity of the generalized force equation for a contracting shell. If this equation holds

$$K = \frac{d}{dt}(m_t v) = v\frac{dm}{dt} \tag{36}$$

since $\frac{dv}{dt} = 0$.

The mass of the electron plus the mutual mass of electron and shell is

$$m_t = \left[\frac{e^2}{6\pi ac^2} + \frac{ede}{3\pi r'c^2}\right]\frac{1}{\sqrt{1-\beta^2}} \tag{37}$$

Hence

$$K = -\frac{ede\frac{dr'}{dt}\beta}{3\pi r'^2 c\sqrt{1-\beta^2}} \tag{38}$$

Which is a force in the same direction as that given by (32) but twice as great.

However, while the force K_1 given by (32) is the only force in the direction of motion that does any *work*, it is not the total force that must be applied to the contracting shell in order to keep its velocity unimpaired. In fact (3) shows that the magnetic field exerts a resultant force on the shell in such a direction as to decrease the velocity. The mechanical force which must be applied to counteract this resistance is

$$\mathbf{K}_2 = -\frac{1}{c}\int de\frac{d\mathbf{r}}{dt}\times\mathbf{H} \tag{39}$$

Substituting the value of de from (21) and that of H from (23) we get upon integration

$$K_2 = -\frac{ede\frac{dr'}{dt}\beta}{6\pi r'^2 c\sqrt{1-\beta^2}} \tag{40}$$

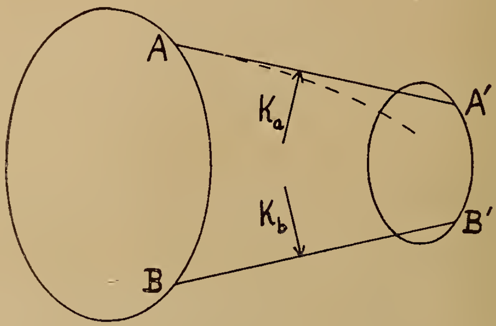
Adding this force to the resisting force due to the electric field as given by (32) we get

$$K = K_1 + K_2 = -\frac{ede\frac{dr'}{dt}\beta}{3\pi r'^2 c\sqrt{1-\beta^2}} \tag{41}$$

which agrees with the expression for the applied force as obtained from the generalized force equation.

At first it may seem surprising that there can be a force on the contracting shell that does no work. A consideration of figure 2 explains the apparent anomaly. The shell AB contracts to A′B′ as it moves along. The charge which follows the path AA′ tends to be deflected along the dotted line by the magnetic field. To prevent this deflection a force K_a must be applied. Since K_a is perpendicular to the direction of motion, it will do no work. Similarly with K_b. However, the resultant of K_a and K_b and of all similar pairs of forces will obviously have the same direction as the motion of the center of the shell and will *not* be zero. While the resultant force at any instant should equal the rate of change of momentum, it is necessary, even in ordinary dynamics, to consider the component forces in finding the work done by a system of forces acting on a deformable body.

FIG. 2.



Summary.

The energy of a moving electron has been calculated by finding the work done in constructing the electron out of charged shells which are shrunk down from infinite size to the surface of the electron, maintaining throughout the process the same velocity as the electron. The work done in contracting these shells, or the potential energy of the electron, is found to be equal to the electric energy of its field. The work done in maintaining the velocity of the contracting shells against the retardation of the field, or the kinetic energy of the electron, is found to be equal to the magnetic energy of the field, but to differ from the expression for the kinetic energy peculiar to Einstein's relativity dynamics.

The resultant force which must be applied to each contracting shell to maintain its velocity is found to be equal to the product of the velocity by the rate of change of the mutual mass of shell and electron, as would be expected from the generalized force equation.

Sloane Physical Laboratory of Yale University,
New Haven, Conn., April, 1915.

Art. X.—*A New Nebraska Mammoth, Elephas hayi*; by Erwin H. Barbour.

On June 23, 1914, the office of the Nebraska Geological Survey was notified that a mammoth jaw had been discovered in the Hurlbert sand pit at Crete, Nebraska, eight blocks east and three blocks north of the center of the town.

An assistant in the department was detailed to visit the spot at once, and through the courtesy of Mr. Hurlbert, secured the mandible and teeth of a mammoth that proved to be new. We wish to propose for this the name *Elephas hayi* in recognition of Dr. Oliver P. Hay, of the Carnegie Institute, who has spent some time in the study of the specimen, and who concurs in the belief that it is new.

The jaw, though finely preserved, was badly broken and damaged in the pit, and although pieces were carried away as relics, they were afterwards returned. Later the surrounding gravel was carefully screened and important additional bits were obtained. The writer also visited the site of the discovery, and finds the sands and gravels to be of considerable extent, and of glacial origin. They undoubtedly represent an interglacial, rather than a glacial stage, and shall be counted Aftonian. The deposit seems to vary in thickness from 10 to 20 feet or more, and probably contains numerous bones. The specimen in question was found 11 feet below the surface. It is reported that a number of years ago, many bones were found extending from the present Hurlbert gravel pit across the newly graded road, particularly in an excavation for the basement of a neighboring building. This leads to the hope that as work progresses additional material may be found.

Associated with this jaw were fragments of a large tusk. The jaw and teeth of an exceptionally large and interesting new Pleistocene horse were found two blocks distant in the same deposit.

The chief distinguishing characters of *Elephas hayi* are: unusual length of mandible; the last molar small, narrow, and anterior to the coronoid; transverse ridges 10 to 11; angle distinct and sharp posteriorly; coronoids uncommonly prominent, deeply pitted, and set very obliquely. Making allowance for sex, age, and individual variation, the mandible of *Elephas hayi*, as compared with any of our well-known mammoths—*E. imperator*, *E. columbi*, or *E. primigenius*—is uncommonly long, justifying the name long-jawed mammoth. The jaw may be counted a primitive character, for longirostral proboscideans preceded the more modern brevirostral forms.

FIG. 1.

FIG. 1. *Elephas hayi*, sp. nov. × 1/8.

Aftonian. Crete, Nebraska. Collections of Hon. Charles H. Morrill, the Nebraska State Museum.

FIG. 2.

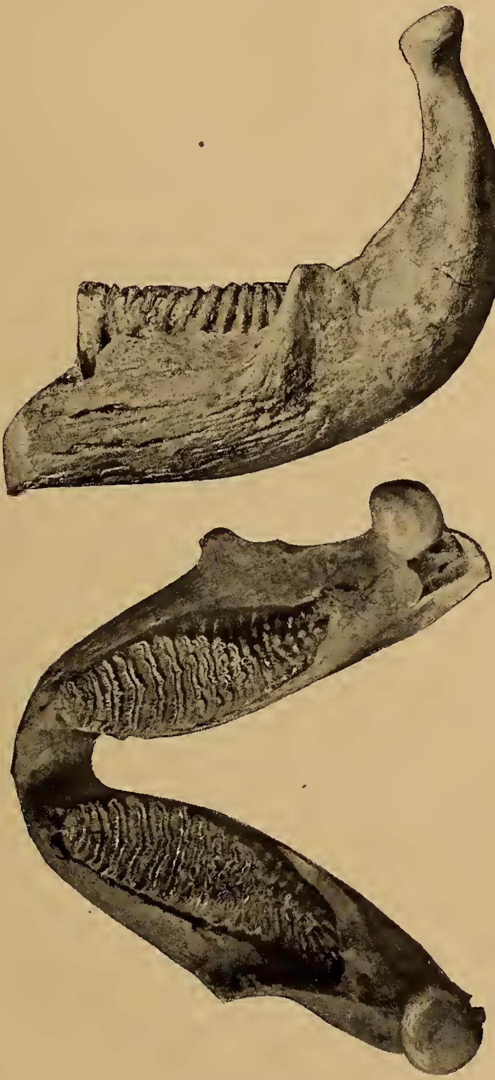


FIG. 2. *Elephas imperator.* × 1/8.

Sutton, Nebraska. Collections of Hon. Charles H. Morrill, the Nebraska State Museum.

In modern elephants and mammoths, the inferior mandibular border is broad and round, and curves without angle into the ascending ramus. Though much the same in *E. hayi*, it is to be noted that the inferior border is somewhat subangular, and that there is a distinct angle which is compressed to a narrow edge posteriorly. This is quite unlike ordinary forms of the genus *Elephas*.

The mandible of *E. hayi* measures 29½ inches (750$^{\mathrm{mm}}$) from the tip of the symphysis to the angle, while the mandible of *E. imperator*, shown in figures 2 and 4, measures 21½ inches (546$^{\mathrm{mm}}$), the difference being 8 inches (203$^{\mathrm{mm}}$). The depth of the jaw at the coronoids is 9½ inches (241$^{\mathrm{mm}}$), that of *E. imperator* 10½ (267$^{\mathrm{mm}}$). Though noticeably longer, the jaw of the Crete mammoth is thinner than that of *E. imperator*. The accompanying sections will give an idea of form, and will show certain fundamental differences.

The coronoid process is conspicuously robust, being 2¾ inches (70$^{\mathrm{mm}}$) through near its base, and an inch (25$^{\mathrm{mm}}$) near the summit. It stands 4 inches (102$^{\mathrm{mm}}$) above the superior mandibular border, and 2 inches (51$^{\mathrm{mm}}$) above the crown of the teeth. It is set more obliquely than in other mammoths. Its inner surface is deeply pitted, and extends from the outer to the inner alveolar border. The coronoids of mammoths and modern elephants are weak and thin as compared with those of *E. hayi*.

The distinguishing character on which this new mammoth must depend is derived, first of all, from the teeth. Especial care was exercised to determine whether the teeth in the jaw of *E. hayi* are penultimate or ultimate molars. If penultimate, a successor should be in evidence in each ramus, but not a fragment of a tooth or plate could be found in the cavities, which were filled with compact sand and gravel; nor could any such fragments be found in the surrounding gravels when screened. Undoubtedly the two teeth are the sixth molars, a point of consequence in this connection.

The teeth are those of a mature individual, with the crowns well worn. Though well cemented and strong, the teeth of *E. hayi* are noticeably small. The postero-anterior diameter is but 9 inches (229$^{\mathrm{mm}}$), and the greatest transverse diameter 3 inches (76$^{\mathrm{mm}}$). A similar tooth of *E. imperator*, shown in figures 2 and 4, exceeds 14 (356$^{\mathrm{mm}}$) by 4 inches (102$^{\mathrm{mm}}$). The dimensions of these teeth agree more closely with those of our earlier Nebraska mastodons than with those of our mammoths. The number of transverse plates is noticeably reduced, for there are but 10 in one tooth, and 11 in the other, with no plates missing. In *E. imperator*, there are 16 to 18 very thick plates; in *E. columbi*, 24 to 26, and even 28 moderately thick plates; and in *E. primigenius*, 18 to 27 thin plates, although fewer than 24 is rare. Ten enamel plates to the decimeter generally indicates *E. primigenius*, 6 to 8 *E. columbi*, and 5 to 6 *E. imperator*. In *E. hayi*, there are 4 and a fraction transverse enamel ridges to the decimeter. The valleys are deep and bordered by highly crenulated enamel ridges. The great anterior prong branches widely and carries 3 plates. The

FIG. 3.

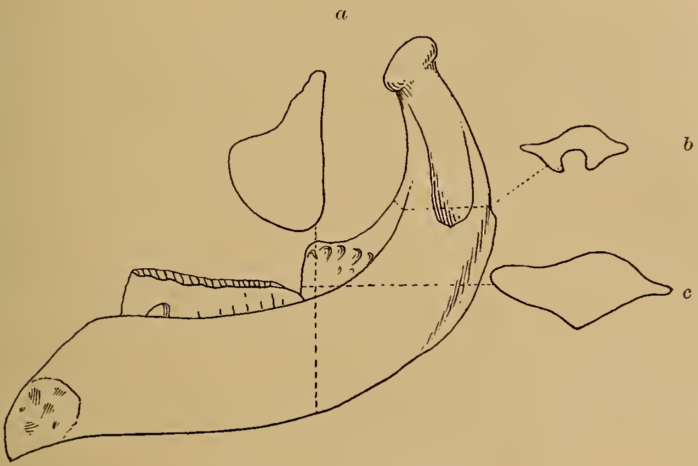


FIG. 3. *Elephas hayi.*

a, vertical section through coronoid; *b*, horizontal section near rim of inferior dental foramen; *c*, horizontal section through coronoid and angle.

FIG. 4.

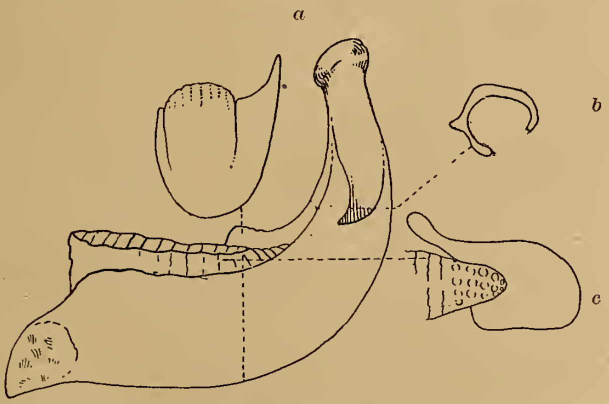


FIG. 4. *Elephas imperator.*

a, vertical section through coronoid and sixth molar; *b*, horizontal section near rim of inferior dental foramen; *c*, horizontal section through base of coronoid and last molar. For comparison with *Elephas hayi*.

teeth lack the symmetrical development common to mammoths. They are noticeably constricted back of the anterior prong, and taper posteriorly to 1½ inches (38$^{\text{mm}}$).

Ancestral proboscideans began with 2 simple transverse ridges to each molar tooth. Later forms, such as the mastodons, had 3, 4, and 5 or more; intermediate forms, such as stegodonts, had 6 to 8 or more; while mammoths had many. In *E. hayi*, there are but 11 transverse ridges at most, the last being small, perhaps a heel. This form seems to be an earlier and more primitive type of mammoth than any other known to the State.

FIG. 5.

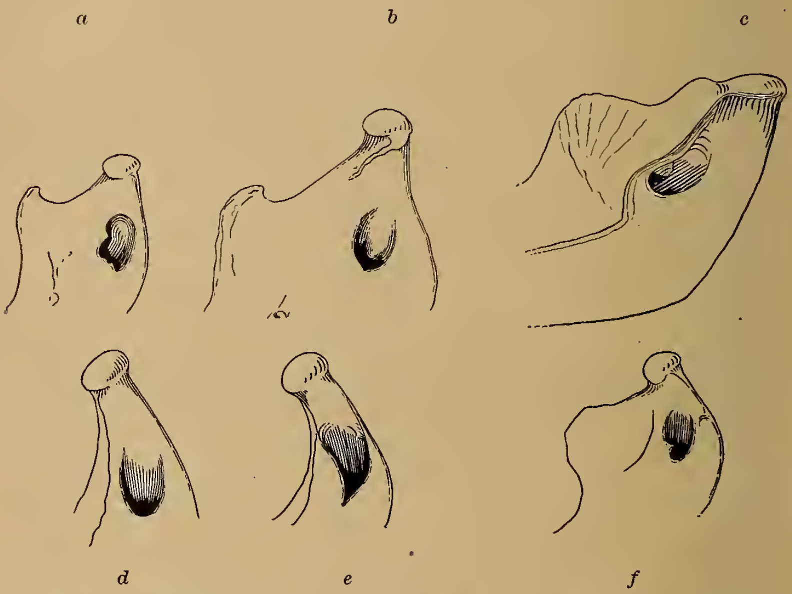


FIG. 5. Ascending rami and inferior dental foramina of certain Nebraska Proboscidea. *a*, *Tetrabelodon willistoni*; *b*, *Tetrabelodon lulli*; *c*, *Eubelodon morrilli*; *d*, *Elephas hayi*; *e*, *Elephas imperator*; *f*, *Elephas indicus*. From specimens in the collection of Hon. Charles H. Morrill, the Nebraska State Museum.

The inferior dental foramen is small, and has a circular border, while in *E. imperator* it is very large and deeply notched, as shown in the accompanying figures. Although inferior dental foramina differ in individuals, and even between opposite sides of the jaw, the differences shown by the cuts are significant. The ascending rami of our proboscideans also vary between wide limits. Judging by the large number of varied Nebraska Proboscidea, multiplication of generic and specific names in this group seems inevitable.

The University of Nebraska, February 15, 1915.

Art. XI.—*A New Gavial from the Late Tertiary of Florida*; by E. H. Sellards.

The crocodilian remains described in this paper, including the anterior part of a cranium and part of a lower jaw, were obtained by Mr. Anton Schneider, general manager of the Amalgamated Phosphate Company, and were by him presented to the Florida State Geological Survey. The specimens are from the Company's mine at Brewster, Polk County, Florida, and were obtained in mining phosphate rock. The deposits in which the fossils are found, the Bone Valley formation, are either of upper Miocene or of lower Pliocene age. The associated fossils, although not fully studied, are known to include rhinoceroses, probably *Teleoceras fossiger* and one or two other species, one or two species of *Hipparion*, and one or two species of mastodons, including apparently the form described as *Mastodon floridanus* by Leidy. Fish and cetacean remains as well as crocodilian teeth are present, the deposits being of shallow water, marine or estuarine origin.

Of the Eusuchia, the sub-order to which is referred some of the late Mesozoic and all of the Cenozoic and recent Crocodilia, four families are recognized as follows: Alligatoridæ, Crocodilidæ, Tomistomidæ and Gavialidæ.* Of these families, the Alligatoridæ and the Crocodilidæ include, with some exceptions among the crocodiles, short snouted species, while the Tomistomidæ and Gavialidæ include long snouted forms. Further distinctions are found in the lower jaw, the symphysis of which, in the Alligatoridæ and Crocodilidæ, is short, never extending according to Gadow beyond the eighth tooth, while in the Tomistomidæ and Gavialidæ the symphysis is long never stopping short of the fifteenth tooth.

That the species described in this paper is to be placed with the gavials rather than with the crocodiles is indicated not only by the long snout and extended symphysis of the lower jaw, but also by the fact that the first mandibular tooth bites on the outside and not on the inside of the upper jaw.

Between the Tomistomidæ and the Gavialidæ distinctive characters are found in the relative extent of the nasals. In the Tomistomidæ the nasals are long and narrow and articulate with the premaxillaries, while in the Gavialidæ these bones are remotely separated from the premaxillaries, from which they are shut off by the maxillaries. Although of the skull only the rostrum is preserved in the Florida material, the position of the nasals, which extend to and are wedged in

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* Zittel, K. A., Textbook of Palaeontology, Eastman's Translation, vol. ii, pp. 217–222, 1902.

FIG. 1.

FIG. 1. *Tomistoma americana.* Superior and inferior view of the rostrum. Extreme tip restored to show the sockets for the large first teeth. The notch for the reception of the first mandibular tooth is but feebly developed. The nasals reach forward to and articulate with the premaxillaries. The sutures not sufficiently evident in the photograph are indicated by broken lines. One-third natural size.

between the backward extending premaxillaries, is distinctive, indicating that this form is to be referred to the family Tomistomidæ.

Of the genera regarded as probably referable to the Tomistomidæ only two are from America, namely *Thoracosaurus* Leidy and *Holops* Cope, both of which are from the upper Cretaceous. The type genus of the family, *Tomistoma*, is known in Europe from the Miocene of Hungary, Malta and Sardinia, and is represented at the present time by recent species found in Borneo, Sumatra and Molucco. From the characters that can now be determined it appears that the Florida fossil is congeneric with these old world forms and accordingly the Florida species is referred to *Tomistoma*, this being the first record of the genus in America. The Florida material derives an added interest, from the fact that it affords evidence of the existence in North America of gavials as late as the Miocene or Pliocene, although the group has since disappeared from the Western Hemisphere. The species is clearly distinct from any heretofore described, and may be known as *Tomistoma americana*.

FIG. 2.

FIG. 2. *Tomistoma americana.* Fragment of the lower jaw showing that the splenials as well as the dentaries enter into the symphysis of the jaw. Specimen No. 2372. One-third natural size.

The writer is indebted to the officials of the National Museum, and especially to Mr. C. W. Gilmore, Assistant Curator of Reptiles, for facilities afforded in comparing related recent and fossil species.

Tomistoma americana sp. n.

The species *Tomistoma americana* is based upon the anterior part of a skull, including the rostrum, from the Bone Valley formation of Florida. The rostrum is much elongated and shows a very slight upward curvature. The teeth, of which the base or sockets of eleven are preserved, are sub-equal in size showing but slight differentiation. The premaxillaries extend on the dorsal surface of the rostrum to a point opposite the third maxillary tooth. The nasals are narrow and are wedged in between the backward projections of the premaxillaries, reaching forward to a point opposite the first maxillary tooth, the nasals and premaxillaries being thus in contact from the first to the third maxillary tooth, or a distance of 10^{cm}. The notch which should receive the first mandibular tooth is feebly developed being scarcely perceptible. The notch or constriction in the jaw which received the fourth mandibular tooth is, however, well developed. Five teeth are present in each premaxillary, the second, which has disappeared from the more specialized species of *Tomistoma*, being in this species well developed, although slightly smaller than the first, third and fourth premaxillary teeth. The first three maxillary teeth are strong; the fourth, however, is reduced and the jaw at this point is slightly constricted for the reception apparently of two strong mandibular teeth. Back of the fourth maxillary tooth the rostrum is again expanded, the fifth and sixth maxillary teeth being strong. Between these teeth is seen a distinctly marked pit for the reception of a mandibular tooth. The sockets for the teeth are directed forward. Although none of the large teeth are preserved, the crowns of young teeth may be seen in several of the sockets. These young teeth show keels. On the young first maxillary tooth the keels lack but little of being on the anterior and posterior sides of the tooth; while those of the fifth and sixth maxillary teeth are more nearly lateral in position. The type of the species is specimen No. 3657 of the Florida State Geological Survey collection.

With this specimen is associated a fragment of a lower jaw (No. 2372) which is probably of this species and accordingly may be designated as the paratype. This fragment on which is seen the sockets of six of the mandibular teeth is of interest since it shows that the splenial takes part in the mandibular symphysis, a feature common to the gavials, but exceptional among the alligators and crocodiles.

Florida Geological Survey,
Tallahassee, Fla.

ART. XII.—*Chlamytherium septentrionalis, an Edentate from the Pleistocene of Florida*; by E. H. SELLARDS.

THE genus *Chlamytherium*, of which *C. humboldtii* is the type species, was established by Lund in 1838 on material from South America.* Distinctive characters of the genus are found in the molar teeth, which are elongated from front to back, the larger teeth being as much as three or four times as long as broad. On the exterior of the molar teeth is a broad furrow which partially divides the crown into an anterior and a posterior pillar. On the inner surface of the tooth is seen two or three faint furrows, which, however, are but faintly seen on the crown. The cross section of the molar is thus that of an ellipse compressed at the center, more strongly so from the outer side. Traversing the central line of the molar teeth from front to back is a thin dark band which is in fact made up of two bands of dark colored dentine placed in juxtaposition, giving an appearance such as would result from the collapse of a cavity the walls of which were lined by a dark band of dentine. Moreover in breaking, the tooth parts along this line, the bands of dentine are sometimes somewhat separated from each other, and in this case, according to Ameghino, the cavity between is filled with cement. Although seldom preserved in the fossils, the exterior of the tooth is said also to have been covered with a layer of cement which is thickest in the lateral furrows. At the base the tooth shows in the fossil condition a large undivided cavity, which narrows upward, becoming closed near the middle line of the tooth, beyond which is the dark band already described.

The lower jaw of *Chlamytherium* is pointed in front and contains nine teeth. Of the teeth the posterior six are molariform in appearance and function, while the anterior three are reduced and are more nearly circular in cross section. In general appearance the jaw is distinctly glyptodont. From the glyptodonts, however, the genus is distinguished not only by the structure of the teeth, which lack the tripartite division of the crown and base, but also by the fact that the ascending ramus of the jaw is inclined gently backward, and does not turn up at a right angle, or at more than a right angle as in the glyptodonts. Moreover, the shield consists of

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* Overs, K. Danske Vid. Selsk, Forh., viii, p. lii, 1838.

In the original description the generic name was written *Chlamytherium* although subsequently Lund as well as others used the form *Chlamydotherium*. In his Bibliography and Catalogue of Fossil Vertebrates (Bull. U. S. Geological Survey, No. 179, p. 581, 1901) Dr. O. P. Hay used the form *Chlamytherium*.

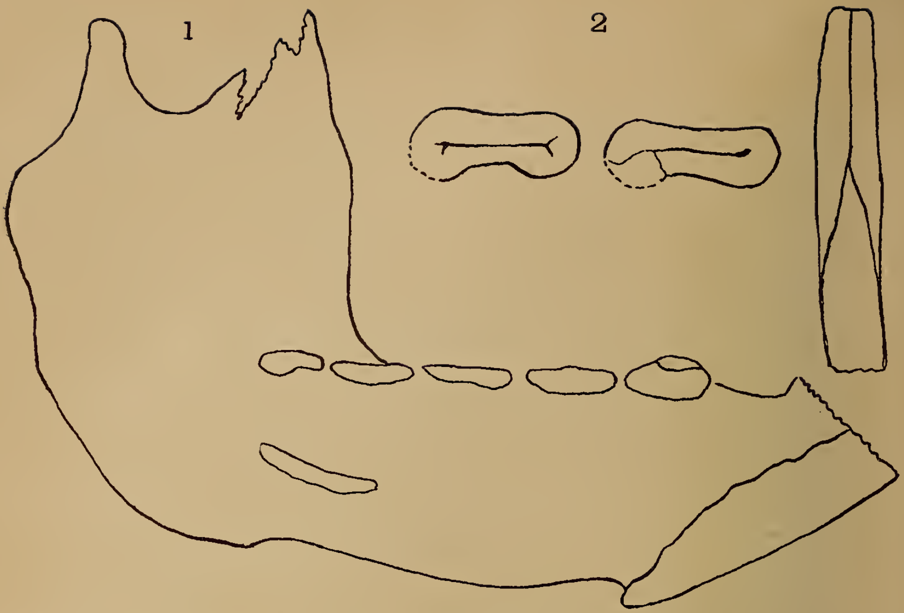

FIG. 1. *Chlamytherium humboldtii*, left jaw, interior view. A tracing taken from Lund's original illustration. One-half natural size.

FIG. 2. *Chlamytherium septentrionalis.* Two teeth from the right lower jaw. At the left, the third tooth from the back of the jaw, presumably the seventh from the front; the grinding surface of the tooth measures 22 by 6^{mm}. At the center, the fourth tooth from the back, presumably the sixth from the front: the grinding surface of the tooth measures 23 by 6^{mm}. At the right, median section through the fourth tooth from the back of the jaw, showing, by diagrammatic section, the cavity at the base of the tooth. All from specimen No. 1722, Fla. Geol. Survey. Natural size. From Vero, Fla.

FIG. 3. *Chlamytherium septentrionalis.* Exterior view of the right jaw, same specimen as fig. 2. Approximately one-half natural size.

FIG. 4.

FIG. 4. *Chlamytherium septentrionalis.* The horizontal ramus of the right jaw viewed from above, showing the molariform teeth. From specimen No. 1722, Fla. Geol. Survey. Approximately four-fifths natural size.

FIG. 5.

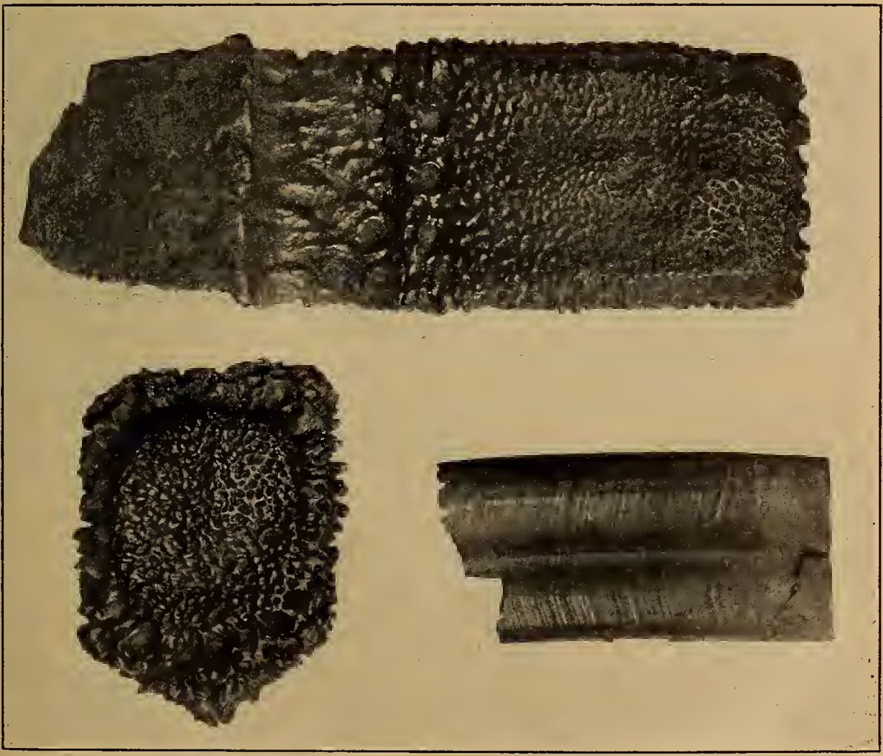

FIG. 5. *Chlamytherium septentrionalis.* At the top of the figure is seen a plate from the movable band, exterior view ; below, at the left, one of the dermal scutes, showing the coarse and rather deep sculpturing that characterizes most of the scutes of this species ; at the right is seen the fourth tooth, counting from the back, of the right lower jaw, viewed from the inner side, showing the two faint furrows and the wavy cross lines of the tooth. From Vero, Fla., Coll. Fla. Geol. Survey. All natural size.

an anterior and a posterior buckler with several movable transverse bands between, similar to those of the armadillos. Although referred to the Dasypoda, the genus is recognized as in many ways intermediate between the armadillos and the glyptodonts.

The presence of the genus *Chlamytherium* in the late Cenozoic deposits of Florida was first made known by Joseph Leidy, to whom was referred dermal scutes of the genus collected on Peace Creek by Mr. Joseph Willcox in 1888. These plates were at first described by Leidy as *Glyptodon septentrionalis* sp. n. Afterwards, however, all of the plates, including the types of *Glyptodon septentrionalis*, were referred to *Chlamytherium* (*Chlamydotherium*) *humboldtii* Lund. Subsequently additional scutes were obtained from other localities in Florida, all which were referred to *C. humboldtii*. By the fortunate discovery of additional material of the genus,

Fig. 6.

Fig. 6. *Chlamytherium septentrionalis.* Right lower jaw viewed from the inner side. One-half natural size. From Vero, Fla., Coll. Fla. Geol. Survey.

The canal, the location of which is seen below the specimen number, is apparently a character of generic, or more than generic value, as it is observed not only on this species but also on *C. humboldtii* and *C. paranense*.

including dermal scutes and one right lower jaw from near Vero, Florida, it now appears that the Florida specimens pertain not to *C. humboldtii*, but to a species distinct from the South American forms. Moreover, after direct comparison of the scutes, I am convinced that the new material from Florida is specifically identical with that to which Leidy originally applied the name *Glyptodon septentrionalis*. It becomes necessary, therefore, to revive Leidy's specific name, the species, however, being referred to the genus *Chlamytherium* and not to *Glyptodon*.

The material now known from Florida representing the species and on which the following description is based includes the following: One right lower jaw found near Vero, collected by Frank Ayers and presented to the State Geological Survey by Isaac M. Weills; also a number of dermal scutes from the same locality; twenty-four dermal scutes from Peace Creek collected by Joseph Willcox and now in the collection of the Wagner Free Institute; also one plate from the movable band obtained by Mr. Willcox from White Beach, Sarasota Bay; one dermal scute from Peace Creek in the collection of the U. S. National Museum, and two dermal scutes taken from Peace Creek by Mr. S. A. Robinson. In addition the Yarman collection of Vanderbilt University contains several scutes of *Chlamytherium* obtained from the Hillsboro River, Florida. The jaw and scutes from Vero may not be from a single individual, although they represent with little doubt a single species.

The deposits from which the *Chlamytherium septentrionalis* is obtained are of Pleistocene age. The fossils associated with this species at the locality near Vero include *Equus*, *Elephas*, *Mammut americanum*, *Megalonyx*, *Tapirus*, and *Odocoileus*, the fauna as well as the conditions of deposition indicating late Pleistocene. The Peace Creek beds include the same fauna although with these is associated some earlier forms, most if not all of which have washed in from the Pliocene and older formations through which the river has cut its channel. The specimens from the Hillsboro River and from White Beach are doubtless of the same age as those from Vero and Peace Creek.

The writer acknowledges his indebtedness to the officials of the Wagner Free Institute, the National Museum and the American Museum for the opportunity and facilities afforded of comparing specimens of this and related species.

Chlamytherium septentrionalis (Leidy).

Glyptodon septrionalis Leidy, Acad. Nat. Sci., Phila., Proc., p. 97, 1889.

Chlamydotherium humboldtii, Lund, Leidy, Wag. Free Inst. Sci. Trans., vol. ii, pp. 24–25, 1889, U. S. Geol. Survey, Bull. 84, p. 129, 1892.

Chlamydotherium humboldtii Lund, Cope, U. S. Geol. Survey, Bull. 84, p. 130, 1892.

Chlamytherium humboldtii Lund, Hay, U. S. Geol. Survey, Bull. 179, p. 581, 1901 (pars.).

Chlamydotherium humboldtii Lund, Trouessart, Catalog. Mammalium, p. 812, 1904 (pars.).

Although presenting the generic characters of *Chlamytherium*, the Florida species is apparently distinct from all of the South American species of that genus that have been described. From *C. humboldtii*, to which species the Florida material has previously been referred, *C. septentrionalis* differs, if we may rely on Lund's figures, in the form and proportion of the jaw, the relative size and position of the teeth, as well as in the sculpturing of the dermal plates. The inferior margin of the jaw of *C. septentrionalis* is full and rounded, while in *C. humboldtii* the margin is noticeably constricted between the angle of the jaw and the symphysis. Moreover, in *C. septentrionalis* the symphysis begins opposite the fifth molar, counting from the back, while in *C. humboldtii* the symphysis is placed opposite or near the anterior margin of the fourth molar from the back. The ascending ramus of the jaw of *C. septentrionalis* is relatively broader and has a slightly more pronounced backward inclination than has that of *C. humboldtii*. The tip of the jaw of the Florida specimen, which should show the anterior teeth. is unfortunately not preserved.

The pittings on the face of the scutes of *C. septentrionalis* are stronger than are those on *C. humboldtii*; the sculpturing also is more strongly marked on the margins of the plates of the movable shield. Moreover, the excellent illustrations of the scutes of *C. humboldtii* given by Lund* do not show the median keel or ridge which characterizes the plates of the movable hands, as well as many of the other dermal scutes of *C. septentrionalis*.

The plates of the movable bands of the two species, and also the dermal scutes, are of approximately the same size. The jaw of *C. humboldtii*, however, as figured by Lund (l. c., Tredje Afhandling, pl. xiv, fig. 1), the outline of which is shown in figure 1 of this paper, is perhaps somewhat larger than that of the Florida specimen, although a second complete jaw subsequently figured by Lund† is no larger than the jaw from Florida, and it is probable that the two species differed little if any in size, being, as estimated by Lund, approximately the size of the modern South American tapir.

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* Lund, P. W., Blik paa Brasiliens Dyreverden för sidste Jordomvæltning. K. Danske Vidensk. Selskabs Anden Afhandl., pl. 1, figs. 7–10, 12, 13; pl. xii, figs. 6, 7, 1841.

† Ibid., Fjerde Afhandling, ix, pl. xxxiv, fig. 9, 1842.

A second species described by Lund from South America, namely, *C. giganteum (C. gigas, C. majus)*, is not only much larger, being approximately the size of a rhinoceros, but has teeth which in cross section are more oval than are those of the Florida species.

Of the five species of this genus from South America described by Ameghino,* one, namely, *C. typum*, has much less strongly sculptered dermal scutes than those of *C. septentrionalis.* A second species, *C. paranense*, of which scutes and parts of the lower jaw are known, includes animals of scarcely more than half the size of those of the Florida species. The structure of the teeth of *C. paranense* is very similar to that of *C. septentrionalis.* The last lower molar of the South American species, however, is set in, and, at the base, is out of line with the other molars. *C. intermedium*, a species intermediate in size between *C. typum* and *C. parenense*, is reported to have been derived from the upper Miocene deposits. The two remaining species, *C. ? extremum* and *C. ? australe*, are reported from yet older deposits and are doubtfully referred to this genus.

The presence in Florida of a species of the South American genus *Chlamytherium* affords another interesting example of the spread of the South American fauna into the United States during the late Cenozoic.

Florida Geological Survey, Tallahassee, Fla.

Art. XIII.—*Bournonite Crystals of Unusual Size from Park City, Utah*; by Frank R. Van Horn and W. F. Hunt.

Introduction.

The senior author of this paper visited some of the mines at Park City, Utah, for a few days in June, 1911. At this time Mr. A. T. Dalley of the Silver King Coalition Mines Company gave the writer a crystal of bournonite. Mr. Dalley was still the owner of a second crystal, which he later presented to the Geological Department of the University of Utah. Previous to this time, the late Albert F. Holden of Cleveland had obtained another crystal from Mr. Dalley which is believed to be the largest crystal of bournonite in existence in the United States, if not in the world. The writer afterward

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*Contribucion al Conocimiento de los Mamiferos Fosiles de la República Argentina, Actas de la Academia Nacional de Ciencias de la República Argentina en Córdoba, Vol. vi, 1889.

found, upon examination of specimens, that the mineral occurred frequently in the ores of the district, where it has been mistaken for tetrahedrite probably for a long period of years. Mr. Maynard Bixby of Salt Lake City, who is an authority on Utah minerals, was not aware of the existence of the mineral at Park City, and the writer has called attention to the new occurrence in another paper.*

Fig. 1.

Fig. 2.

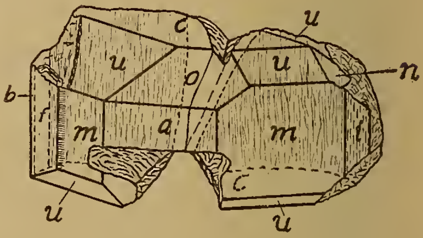

Fig. 1. Photograph of Bournonite Crystal No. 2 (natural size), from Case Collection. Found at Silver King Mine.

Fig. 2. Crystal No. 1, from Holden Collection now at Harvard University.

Fig. 3.

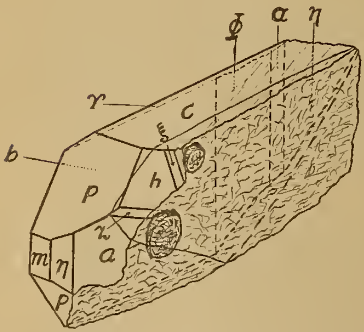

Fig. 4.

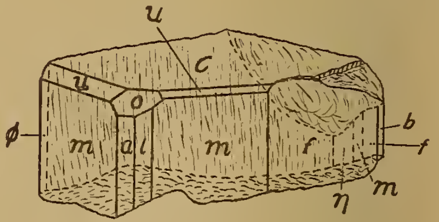

Fig. 3. Drawing of Crystal No. 2, from the collection of Case School of Applied Science. This drawing shows the right-hand side of the crystal, while fig. 1 is a view of the left-hand side.

Fig. 4. Crystal No. 3, from the collection of the University of Utah.

The senior writer became much interested in this new locality for bournonite, and arranged to borrow the other two

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* The Occurrence of Bournonite, Jamesonite, and Calamine at Park City, Utah, by Frank R. Van Horn, Bulletin 92, Amer. Inst. of Min. Eng., August 1914, pp. 2223, 2230.

crystals which have been mentioned previously. Professor F. J. Pack of the University of Utah very kindly loaned the one in his possession to us for investigation. After the death of Mr. Holden, his magnificent collection was willed to Harvard University, and Professor John E. Wolff was good enough to send us the Holden crystal for study. The crystallographic work on this paper was performed entirely by the junior author in the Mineralogical Laboratory of the University of Michigan.

OCCURRENCE OF THE BOURNONITE.

Bournonite, in general, is a very rare mineral and has been found at only three or four places in the United States, so that the mere fact of finding it at Park City is a matter of interest. The discovery of crystals of large size lends additional interest to the occurrence. The three crystals were found on the 1300 ft. level of the Silver King Coalition Mine, and as far as known are the only crystal individuals from the district in existence. The dimensions and weights of these specimens follow :

	Dimensions in Centimeters	Weight in Grams
No. 1 Holden Collection, Harvard,---	$3\frac{1}{2} \times 3\frac{1}{2} \times 6$	185·0
No. 2 Case School of Applied Science,	$2 \times 2\frac{1}{2} \times 4$	61·7
No. 3 University of Utah,----------	$1\frac{1}{2} \times 1\frac{1}{2} \times 3\frac{1}{2}$	44·4

Other bournonite crystals which are much smaller, according to Mr. Dalley, have been found at the Silver King Mine in quartzite associated with galena, pyrite, sphalerite, and jamesonite. One specimen of bournonite was also found in the lower levels (1,000–1,200 ft.) of the Daly West Mine. Associated with this mineral are pyrite and coarse cleavable galena; on the upper and left-hand portion are rough, somewhat tabular crystals of bournonite, one of which measured approximately $2 \times 1 \times 3^{cm}$. These grade down into the massive material. In the lower right-hand corner of the specimen there is coarse cleavable galena, while on the left in cavities there are small pentagonal dodecahedrons of pyrite. As yet, the writer has not seen bournonite and tetrahedrite on the same specimen, and it is an interesting conjecture as to whether both minerals occur together, or are always found apart, and possibly at different depths.

CHEMICAL COMPOSITION.

Since all bournonite specimens, except the three large crystals, were called tetrahedrite, it was deemed advisable to prove the presence of the former mineral from a chemical standpoint. Accordingly portions of some of the crystals together with part of the massive mineral were detached, and analyzed by Dr. W. R. Veazey of the Chemical Department of Case School of Applied Science. The results of this analysis follow:

	Theoretical composition of Bournonite $PbCuSbS_3$	Analysis of Daly West Mineral	Combining Weights	Ratio
Pb	42·54	43·18	0·209	1·009
Cu	13·04	13·14	0·207	1·000
Sb	24·64	25·03	0·208	1·004
S	19·77	19·59	0·611	2·951
	100·00	100·94		

Sp. Gr. 5·829

The ratio given by the Park City mineral conforms very nearly to the composition required by the formula $PbCuSbS_3$, and, therefore, leaves no doubt that the mineral is actually bournonite. Furthermore, the specific gravity, which was found to be 5·829, is about the average obtained from specimens of the mineral at other localities. Before the blowpipe, the mineral gives the usual reactions for sulphur, antimony, lead, and copper.

Physical Properties.

The color and streak of the mineral are blackish lead-gray to iron-black. The streak seems to be one of the means of distinguishing it from tetrahedrite at Park City, as the powder of the latter is usually slightly reddish brown. No cleavage is noticeable, and the fracture is almost conchoidal. The mineral is brittle. The hardness is under 3, and the specific gravity, as has been mentioned, is 5·829. The luster is a brilliant metallic on a fresh fracture, while that of the crystals is mostly dull.

Crystallography.

Special interest is attached to the three bournonite specimens submitted for crystallographic orientation on account of the unusually large size of the crystals, the dimensions of which have been previously given. In each instance, the specimens examined were broken crystals, and the size of the original complete forms might well have been from 25 to 50 per cent greater than the present dimensions. The faces were for the most part dull and very rough, thus rendering reflections obtained in the regular manner with a reflecting goniometer impossible.

Measurements were secured, however, by means of the contact method, and for the means employed, the fair agreement of the observed values with the corresponding calculated angles leaves little doubt as to the identity of the forms cited below. When the crystal faces were quite small, and the surface contact unreliable, small pieces of cover glass were cemented to the surfaces in question, and reflections obtained in the usual manner.

Crystal No. 1.—Crystal No. 1 (Holden Collection) was the largest of the three specimens examined, and is shown in fig. 2. Unfortunately it had been broken in two, and before complete measurements could be obtained, the fractured surfaces were glued together, and finally supported by plaster of paris, (the full and long dashed line on the faces *o*(101), and *a*(100) represents the glued contact, while the unshaded space between the short dashes represents the plaster cast). The specimen thus reconstructed was short prismatic in development, and revealed the following 9 crystal forms: the pinacoids, *a*(100), *b*(010), *c*(001); the prisms, *m*(110), *i*(130), *f*(120); the domes, *o*(101), *n*(011); and the pyramid *u*(112.) The angular measurements obtained, as well as the corresponding theoretical values are given in the following table:

	Contact Measurements	Calculated Angles
$m:m = (110) : (1\bar{1}0)$	87° 30′	86° 20′
$f:f = (1\bar{2}0) : (\bar{1}\bar{2}0)$	56	56 8
$i:a = (130) : (100)$	71	70 26
$o:a = (101) : (100)$	47	46 17
$c:u = (001) : (112)$	32	33 15
$c:n = (001) : (011)$	43	41 54
$n:m = (011) : (110)$	63	62 49

Crystal No. 2—Crystal No. 2 (Case Collection) illustrates a prismatic type of development in the direction of the brachy axis ($\breve{a}$). A drawing of this crystal is shown in fig. 3. The right-hand side of this crystal was more or less broken off, and a photograph of the opposite, or more perfect side, is shown in fig 1, with the basal pinacoid, *c*(001) at the top, and the macropinacoid, *a*(100) on the right. This specimen had been glued together at some time previous to its arrival for crystallographic orientation (the full and long dashed line on the faces *c*(001), *h*(203), *p*($2\bar{2}3$), and *a*(100) represents the glued contact). This specimen was found to contain 12 forms which was more than were observed on either of the other crystals as follows:—the pinacoids, *a*(100), *b*(010), *c*(001); the prisms, *m*(110), η(310), Φ(140), *a*(230); the domes, *z*(201), *h*(203), γ(023); and the pyramids, *p*($2\bar{2}3$), and ξ(214). The forms were identified, and their relationship established on the basis of the following measurements:

		Contact Measurements	Calculated Angles
$h:a$	$= (203) : (100)$	57°	57° 29′
$z:a$	$= (201) : (100)$	28	27 36½
$\xi:c$	$= (214) : (001)$	26° 30′	27 50
$p:c$	$= (2\bar{2}3) : (001)$	40	41 9
$\gamma:b$	$= (0\bar{2}3) : (0\bar{1}0)$	58	59 7½
$m:a$	$= (1\bar{1}0) : (100)$	43	43 10
$\eta:a$	$= (3\bar{1}0) : (100)$	18	17 22
$\Phi:b$	$= (\bar{1}\bar{4}0) : (0\bar{1}0)$	15	14 56
$\alpha:b$	$= (\bar{2}\bar{3}0) : (0\bar{1}0)$	36	35 24
$\eta:b$	$= (\bar{3}\bar{1}0) : (0\bar{1}0)$	71 30	72 38
$p:p$	$= (2\bar{2}3) : (2\bar{2}\bar{3})$	98	97 42

Crystal No. 3.—Crystal No. 3 (Utah Collection) also shows a short prismatic habit similar to No. 1. A drawing of this crystal is shown in Fig. 4. The forms observed were all large, and well developed, especially the prisms, *m* and *f*, .and the basal pinacoid *c*. The 10 crystal forms present were the pinacoids, *a*(100), *b*(010), *c*(001); the prisms, *m*(110), *l*(320), *f*(120), Φ(140), *η*(310); the dome, *o*(101); and the pyramid, *u*(112). The angular measurements obtained are listed below :

		Contact Measurements	Calculated Angles
$m:m$	$= (110) : (1\bar{1}0)$	87°	86° 20′
$l:a$	$= (320) : (110)$	31	32 1
$f:f$	$= (120) : (\bar{1}20)$	57	56 8
$f:b$	$= (120) : (010)$	29	28 4
$\Phi:m$	$= (\bar{1}\bar{4}0) : (1\bar{1}0)$	62	61 46
$c:o$	$= (001) : (101)$	43	43 43
$c:u$	$= (001) : (1\bar{1}2)$	33	33 15
$\eta:b$	$= (\bar{3}10) : (010)$	72 30′	72 38

Crystals No. 1 and No. 3, in general, resemble those from Neudorf in the Harz, and Nagyag in Hungary, except that they are inclined to be somewhat more tabular, and that the macropinacoid is less developed. Crystal No. 2 seems to be of different habit than crystals from other localities in its distinct prismatic development in the direction of the brachy axis. The habit of all three crystals is quite different from certain specimens which the writer has recently seen from Cornwall, England; Horhausen, Prussia; and Přibram, Bohemia.

Mineralogical Laboratories
Case School of Applied Science and
University of Michigan
January, 1915.

ART. XIV.—*The Age of the Castile Gypsum and the Rustler Springs Formation;*[*] by J. A. UDDEN.

IN 1904, Richardson described two formations in Culberson County, Texas, the Castile Gypsum, known to be at least 300 feet thick, and the Rustler formation, some 200 feet thick. He found them extending in a continuous broad belt from the New Mexico border southward to within 15 miles of the Texas and Pacific Railway, the Rustler formation overlying the Castile. He found that the Castile formation is separated from the Delaware Mountain formation (Permian) by an unconformity.[†] From the few fossil fragments which were secured from these formations, he was unable to draw definite conclusions as to their probable age, and he stated in his report that "the age of the Rustler formation is not known." Neither could he make any definite statement as to the age of the Castile formation. His descriptions are the best we yet have. Although he searched for fossils in all exposures examined, only a few poorly preserved fossils were found. Dr. T. W. Stanton, who examined one fossil, found that it might be a Mytilus or a Myalina. Dr. F. H. Knowlton reported on some poorly preserved plant remains as probably being of Mesozoic age.

On Willis' geologic map of North America, the area of the outcrop of these formations is represented as Permian, and in his Index to the Stratigraphy of North America, he states that "recent work has shown that the Castile Gypsum and Rustler formation are parts of the group of red beds of Pecos Valley, which are of Permian Age." He cites Richardson's paper: "Stratigraphy of the upper Carboniferous in West Texas and Southeast New Mexico."[‡] It appears that Richardson in this paper refers these two formations in question to the red beds, mainly on the basis of their lithologic character, and on field work by other geologists who have traced the red beds around the Staked Plains from New Mexico to Oklahoma and to the Pecos Valley in Texas.

The Mesozoic as well as the Paleozoic formations are poorly exposed in this region, and all who have worked here have recognized the difficulties attendant on making correct correlations between distant and limited outcrops, in beds that rarely yield any fossils.

It seems pertinent to place on record the finding of some fossils in the Castile formation, which in the writer's opinion

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[*] Published by permission of Dr. W. B. Phillips, Director of the Bureau of Economic Geology and Technology, University of Texas, Austin, Texas.

[†] University of Texas Mineral Survey, Bulletin 9, pp. 43–45.

[‡] This Journal (4), vol. xxix, p. 325, 1910.

indicate that the Castile Gypsum is not Permian, and show that the Castile Gypsum is not a stratigraphic unit, but contains considerable amounts of marly clay in separate beds.

In the latter half of 1914 the Troxel Oil Company made a test hole for oil near the center of the south line of Survey 24, Block 110, on the Public School Lands in Culberson County. This is about one mile east of Rustler Springs. Mr. C. R. Troxell has furnished the writer a set of cuttings from this exploration. A description of these cuttings is as follows:

Description of Samples of Cuttings from Troxel Well No. 1, located near the south line of Survey No. 24, Block 110, Public School Lands, Culberson County, Texas.

	Depth in feet below surface.	
	From	To
White gypsum. Slight effervescence with acid	4	8
Dolomite, gray and yellow, of a fine, uniformly sized crystalline texture. In thin section it shows scattered porosities and minute yellow streaks or blotches believed to be bituminous. The sample contains some black, some gray, and some white quartz. Pyrite and gypsum are present	42	58
Mostly yellow and in part dolomitic limestone. In thin section this is seen to contain fine sand and some other clear, transparent particles. Some is porous and contains black specks of pyrite. Pyrite and gypsum, some fibrous, are present. Some fragments of red and yellow sandy gypsum noted	74	90
Gypsum, mostly coarse-grained, at		105
Red shale, with some gypsum, fragments of limestone and some dark quartz pebbles	115	123
Gray marly material, with many fragments of dark dolomite, some fine sandstone having a calcareous cement, a yellow sandy limestone, gypsum, pyrite and quartz sand. The dark dolomite contains transparent angular quartz grains and some scattered needle-like crystals, also traces of fossils, and has faint reddish bituminous (?) streaky blotches. The crystals in the dolomite are from 0·005 to 0·01 mm. in diameter. Among the finer fragments of the sample were found several foraminifera which are unlike Paleozoic forms, and resemble *Textularia globulosa* Ehrenberg, *Globigerina bulloides* d'Orbigny, *Bulimina pupoides* d'Orbigny, *Anomalina ammonoides* Reuss, Nodosaria sp.	141	145

	Depth in feet below surface.	
	From	To
Dark gray to yellow dolomite, much gypsum, some quartz sand and pyrite. Fumes of sulphur and bituminous matter were given off when heated in closed tube. The dolomite is compact, but in some fragments small round pores, suggesting organic origin, were seen. There are scattered minute black specks, probably pyrite	155	165
Red and green shale, dolomitic limestone and gypsum. Some gypsum is fibrous, evidently from thin layers. The sample contains some small pebbles of vein quartz and a few grains of pyrite. There is also some light gray limestone. Heated in closed tube, fumes of sulphur and bitumen are given off	165	175
Brownish gray shale and dark gray dolomite, some red or yellowish limestone, considerable gypsum, some quartz grains, some pyrite.* A small crystal of quartz was noted and a Foraminifer like *Textularia globulosa*	180	195
Red shale, dark gray dolomite, and a few fragments of red limestone, gypsum, rounded quartz grains, and pyrite. One quartz crystal noted. Fumes of sulphur, bitumen and ammonia noted on heating one part of the sample in closed tube. Another sample of the dolomite gave much oil and gave strong fumes of ammonia	165	209
Gray marly shale, with some fragments of dark dolomite in part impregnated with pyrite, some yellow limestone, gypsum, and a few grains of quartz. Forms like *Globigerina bulloides* and *Textularia globulosa* quite abundant. *Bolivina* like *punctata* d'Orbigny noted and a small fragment of a test like *Textularia turris* d'Orbigny	209	213
Dark dolomite and yellow limestone, much gypsum, some quartz grains, and pyrite. Fumes of sulphur, bitumen and a trace of ammonia noted on heating in closed tube	213	240
Dark gray dolomite with a little gypsum, and a few grains of quartz and pyrite. Sulphur and bituminous fumes were given off when heated. The dolomite contains more or less angular sand and the dark color is due to pyrite, disseminated in very fine cubic crystals. The sample contains Textularia and Globigerina, perhaps from overlying shales		265

	Depth in feet below surface.	
	From	To
Gypsum and dark gray dolomite. The sample contains a few scattered grains of quartz. Sulphur and bituminous fumes were given off when heated in closed tube		275
Gypsum containing dark dolomite and a few scattered grains of quartz and pyrite. Sulphur and bituminous fumes were given off when heated		296
Gray dolomite, with a few fragments of gypsum, quartz and pyrite. Fumes of sulphur and bitumen noted on heating in closed tube	327	335
White gypsum, some dolomite and a few quartz grains and scattered grains of pyrite, at		375
Gray dolomite, white gypsum, and a few grains of quartz. Fumes of sulphur noted on heating. Below		400

The location of this boring is in the west slope of the Rustler Hills, where the general dip of the Rustler formation clearly

FIGS. 1–14.

FIG. 1. Foraminifera from marls interbedded with the Castile Gypsum in the Troxel oil test No. 1, Survey 24, Block 110, Public School Lands, Culberson County, Tex. Tentative identifications, made by the author, are as follows: 1, 2, *Globigerina bulloides* d'Orbigny (?), depth 141–145 ft.; 3, same, depth 209–213 ft.; 4, 5, *Textularia globulosa* Ehrenberg (?), depth 141–145 ft.; 6, 7, same, depth 209–213 ft.; 8, 9, 10, *Bulimina pupoides* d'Orbigny (?), depth 141–145 ft.; 11, *Bolivina punctata* d'Orbigny (?), depth 209–213 ft.; 12, *Anomalina ammonoides* Reuss (?), depth 141–145 ft.; 13, 14, Nodosaria, sp., depth 141–145 ft.

is to the east. It is evident that the greater part of the exploration is through the Castile Gypsum, which is interbedded with red shale, yellow dolomite, and some gray marl. In this gray marl the foraminifera were found, recurring in at least three such beds, at 141–145, 180–195, and at 209–213 feet below the surface. The nature of the ground shown by these samples corresponds with the descriptions in the driller's log, which is not available for publication in full. The upper 300 feet were described mostly as gypsum, red clay with some gray marl, and yellow limestone (dolomite), variously interbedded.

The accompanying figure shows most of the foraminifera found in these samples. I have seen what appears to me to be identical forms in the basal Comanchean at other points in this part of this state. On the other hand, I have examined many foraminifera from the Carboniferous, including the Permian, without ever finding any assemblage of forms at all like the lot found in these gray marls.* It seems to me they are undoubtedly Mesozoic, demonstrating the post-Permian age of both the Rustler Spring formation and of the Castile Gypsum. Gypsum beds associated with red and gray marls are known to lie near the Jurassic east of the Finlay Mountains in El Paso County, of this state, and I believe that the Castile Gypsum and the Rustler Springs formation will be found to be equivalents of these beds, whether Comanchean or of earlier age.†

University of Texas,
Austin, Tex.

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* Bulletin University of Texas, No. 363, pp. 72–81.

† Not wishing to rely solely on my own identification of these fossils, some material was submitted to Dr. Joseph A. Cushman, who kindly examined the same. He says that it contains scattered foraminifera which are more likely to be Mesozoic than Paleozoic; that they are almost entirely Globigerinidæ, a family which is rare or wanting before the Mesozoic. "In this lot they are very clearly shown and I certainly should say, Cretaceous."

I have also submitted a small sample of the foraminifer-bearing cuttings from the Troxel boring to Mr. G. B. Richardson, of the U. S. Geological Survey, and he has kindly furnished for publication with this article a statement anent the questions involved in the correct stratigraphic determination of the Rustler and Castile formations. A desire to throw whatever little new light there may be on an obscure subject, is responsible for this paper. Mr. Richardson's communication is as follows:

Dear Doctor Udden:

Replying to your request for a statement from me concerning the age of the Rustler formation and Castile gypsum:

Clearly more direct evidence of the age of these formations is much to be desired, and I am interested in your discovery of foraminifera. But it seems to me the question may be raised whether present knowledge of minute Mesozoic and Paleozoic foraminifera is sufficient to warrant their use in critical age determinations.

I have thought such evidence as we have indicates the Permian age of these formations. They occur in the lower part of a distinctive group of rocks which outcrop in the valley of Pecos River in southeast New Mexico and west Texas, which have been referred to as the "red beds of Pecos Valley." These red beds form part of an east-dipping series and are underlain on the west, on the flanks of the Guadalupe and Delaware Mountains, by the Guadalupe Group, and on the east, in the escarpment of the Staked Plains, are overlain by the Dockum formation. The Dockum formation is assigned to the Triassic on the evidence of vertebrate bones. But the precise position in the upper Carboniferous of the Guadalupe Group, which contains a unique fauna, remains to be determined. It is assigned to the Permian by Girty.

The "red beds of Pecos Valley" consist of vari-colored, chiefly red, sandstone and shale and interbedded lenses of magnesian limestone and gypsum at least 1600 feet thick. The base of the red beds, considered as the lowest occurrence either of red strata or of gypsum, is not a constant horizon because the stratigraphic position of the red-colored rocks varies along the strike. Very few fossils, shells, and determinable plant remains have been found in these rocks. Concerning the shells which I collected from limestone in the Rustler Hills, Texas, from a horizon presumably above the mouth of the well from which you obtained the foraminifera, G. H. Girty reports: "Two forms are included in this collection, one of them suggesting by its shape a small Myalina, the other being perhaps a Schizodus and having the general shape of *Schizodus harei.*" T. W. Stanton reports that in his opinion these shells are Paleozoic. The best collection known to me from the "red beds of Pecos Valley" was made by Beede, who found shells in a limestone lens near Lakewood north of Carlsbad, New Mexico, which he correlates with the fauna of the Quartermaster and Woodward formations, parts of the well-known Permian red beds of Oklahoma and north Texas.

I hope you will succeed in collecting more fossils from these rocks.

Yours very truly,
G. B. RICHARDSON.

Washington, March 30, 1915.

Art. XV.—*On the Determination of Lead as Sulphite*; by George S. Jamieson.

It has been known for a long time that lead sulphite was a very insoluble compound, but it remained for V. N. Ivanov* to show that very small amounts of lead could be detected by precipitation as the sulphite. He found a 2 per cent solution of acid sodium sulphite most suitable, because this reagent could be employed for the detection of lead in the presence of iron, nickel, silver, copper, calcium, magnesium and aluminum. Barium must not be present as it is precipitated under the same conditions as lead.

Since it appears that this reaction has never been used for the quantitative estimation of lead, the following investigation was made in order to determine the conditions under which lead could be precipitated and weighed as the sulphite. It was found that lead could be precipitated quantitatively from a slightly acid solution with sodium or ammonium bisulphite, or even with aqueous sulphurous acid, if the acidity of the solution is carefully controlled. When a solution contains much acid it should be almost neutralized with ammonium hydroxide before attempting to precipitate the lead.

For convenience, a solution of lead acetate was prepared which contained 7·8320 grams of lead and 10 grams of actual acetic acid in 1000^{cc}. Measured quantities of this solution was taken in beakers and diluted to about 100^{cc}. To each solution an excess of a 2 per cent solution of sodium bisulphite was added. The solutions were thoroughly stirred and allowed to settle for an hour or longer. The precipitates were filtered on Gooch crucibles and thoroughly washed with cold water. It is important for satisfactory washing not to allow all the liquid to pass out of the crucible until the washing is completed. The crucibles containing the lead sulphite were dried at about 150° C. for an hour. The drying is rapid and the weight very constant at this temperature.

The following results were obtained:

No.	cc of Pb sol.	Pb taken	Wt. of $PbSO_3$	Pb found	Error
1	25·0	·1958	·2712	·1954	—·0004
2	22·0	·1724	·2394	·1724	·0000
3	22·0	·1724	·2390	·1723	—·0001
4	30·0	·2350	·3262	·2352	+·0002
5	30·0	·2350	·3262	·2352	+·0002
6	20·0	·1566	·2175	·1567	+·0001
7	19·95	·1562	·2165	·1561	—·0001

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* Chem. Ztg., xxxviii, 450, 1913.

Another series of experiments was made using measured quantities of a lead nitrate solution which contained 7·3950 grams of lead and 5 grams of actual nitric acid in 1000^{cc}. The lead was precipitated with a solution of sulphurous acid which contained 36·8 grams of sulphur dioxide per liter. In some of the experiments, sodium acetate was added after precipitating the lead sulphite, as indicated in the following table of analyses:

No.	cc of Pb sol.	Pb taken	Wt. of $PbSO_3$	Pb found	Error	$NaC_2H_3O_2$ sol. 10%	cc of SO_2
1	20·15	·1489	·2071	·1493	+·0004	----	18
2	15·0	·1108	·1530	·1106	—·0002	----	15
3	25·0	·1850	·2550	·1839	—·0011	----	20
4	20·05	·1482	·2056	·1483	+·0001	10	15
5	25·10	·1856	·2576	·1858	—·0002	10	18
6	25·0	·1850	·2563	·1848	—·0002	----	18
7	20·0	·1478	·2045	·1475	—·0003	----	18
8	10·0	·0739	·1027	·0740	+·0001	10	8
9	10·1	·0747	·1034	·0746	—·0001	10	16
10	10·0	·0739	·1027	·0740	+·0001	20	24

In the first three analyses given above the lead sulphite was filtered ten minutes after adding the sulphurous acid. In experiments 8 and 9 the precipitates were allowed to settle an hour before filtration, while the others were allowed to stand over night. In dealing with unknown quantities of lead and free acid, it is safer to add some sodium acetate. Also it should be observed that it is possible to have such an excess of sulphurous acid that it will exert a solvent action on the lead sulphite.

Several experiments were made in order to determine the conditions under which it would be possible to precipitate lead sulphite quantitatively from solutions containing considerable free acid. It was found that it was only necessary to neutralize the free acid with ammonium hydroxide. However the solution should be left slightly acid so that when the lead is precipitated it will separate in a satisfactory condition for filtration.

The following results were obtained by precipitating the lead with a solution of sodium bisulphite after the acid (10^{cc} HNO_3) had been nearly neutralized:

No.	Pb taken	Wt. of Pb SO_3	Pb found	Error
1	·1117	·1554	·1120	+·0003
2	·1479	·2049	·1478	—·0001
3	·1845	·2565	·1849	+·0003
4	·1482	·2060	·1485	+·0003
5	·1479	·2046	·1476	—·0003

In attempting to precipitate lead as sulphite in the presence of copper it was observed that high results were always obtained when following the directions given above. The error was apparently due to the precipitation of some lead sulphate as the precipitates were found to be free from copper. After much experimentation it was found that a satisfactory separation of the lead could be obtained if care was taken to filter the lead sulphite within about an hour after precipitation. It was found best to filter the solution, leaving as much as possible of the precipitate in the beaker. After washing the precipitate once with about 10^{cc} of water and decanting again, it was heated for 5 minutes with 10–15^{cc} of a strong solution of ammonium sulphite. Then the precipitate was transferred to the crucible and washed thoroughly with water and dried. The ammonium sulphite was prepared by passing sulphur dioxide gas into a solution (1:1) of ammonium hydroxide until it was strongly acid and adding enough more of ammonia to neutralize the solution.

The following results were obtained:

No.	Pb taken	Cu taken	Pb found	Error
1	·1004	·1554	·1014	+·0010
2	·1513	·2331	·1517	+·0004
3	·1505	·2331	·1512	+·0007
4	·0100	·3885	·0101	+·0001
5	·1405	·1941	·1405	·0000
6	·1405	·1941	·1413	+·0008
7	·1204	·2331	·1201	—·0003
8	·1204	·2331	·1200	—·0004

Four analyses were made by simply adding an excess of sodium bisulphite and allowing the precipitate to settle in most cases for several hours before filtration.

No.	Pb taken	Cu taken	Pb found	Error
1	·1566	·1554	·1598	+·0032
2	·1566	·1554	·1606	+·0040
3	·0739	·3885	·0752	+·0012
4	·1471	·2331	·1499	+·0020

An attempt was made to determine lead as sulphite in the presence of calcium, but calcium sulphite was found to be partially precipitated along with the lead, although a calcium solution gave no precipitate with sodium bisulphite even after standing two days.

It was found that lead could be readily separated from zinc as shown by the following experiments:

No.	Pb taken	Zn taken	Pb found	Error
1	·1183	·1791	·1187	+ ·0004
2	·1174	·1194	·1170	— ·0004

These two experiments would indicate that lead can be separated by means of sodium bisulphite without special precautions from those metals (except the alkali earth metals) which are not reduced by the sulphite.

It will be observed that this method could be applied with advantage to the precipitation of lead from solutions containing acids other than sulphuric, because, as shown above, it is only necessary to nearly neutralize the acid with ammonia instead of removing it by evaporation with sulphuric acid, which is the usual procedure with the sulphate method.

Several attempts were made to titrate lead sulphite with potassium iodate in the presence of strong hydrochloric acid, but as the results obtained were always somewhat low, it was found preferable to weigh the precipitate.

Sheffield Chemical Laboratory, Yale University,
May 20, 1915.

Art. XVI.—*The Crystallization of Haplobasaltic, Haplodioritic and Related Magmas*; by N. L. Bowen.

Introduction.

Basalt may consist essentially of labradorite and monoclinic pyroxene and, if the nature of the plagioclase is regarded as the determining factor, a mixture of andesine and monoclinic pyroxene may be called diorite, though commonly diorites favor hornblende rather than pyroxene. In their essentials, then, the mixtures of diopside with the plagioclases, whose thermal behavior is treated in the present paper, may be regarded as basaltic, dioritic and so forth, according to the nature of the plagioclase. The mixtures are, however, basalt, diorite and so forth reduced to their simplest form, for the pyroxene is pure, theoretical diopside, and the plagioclase pure, lime-soda feldspar free from potash. I have referred to the mixtures, therefore, as haplobasaltic and haplodioritic,* preferring to emphasize in the title the petrologic aspect of the investigation rather than its physico-chemical aspect. The artificial mixtures are, moreover, believed to be sufficiently close to basaltic and other magmas to throw considerable light on the crystallization of these natural mixtures.

Though five oxides, SiO_2, Al_2O_3, MgO, CaO and Na_2O, enter into the composition of the mixtures studied, yet all the phases appearing can be expressed quantitatively in terms of the three components albite, anorthite and diopside. From the phase-rule point of view, then, the mixtures studied constitute the ternary system: diopside-anorthite-albite.

Method of Working.

In studying equilibrium in the various mixtures the quenching method was used exclusively. By this method of sudden chilling the phases present at the measured furnace-temperature are fixed and examined under the microscope at leisure. Liquid becomes a glass, crystals remain as such and exhibit their distinctive properties, with the result that the phases present at all desired temperatures can be readily determined. Equilibrium is assured by making the time of holding at the constant furnace-temperature sufficiently long.

The quenching system was calibrated against the following fixed points: gold–1062·5, Li_2SiO_3–1201°, diopside–1391·5°, anorthite–1550°.

In making up the mixtures the following ingredients were used: Na_2CO_3 dried at 300°, Al_2O_3 purified by boiling with

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* From the Greek ἁπλόος = simple.

NH_4Cl solution, MgO obtained by igniting the precipitated carbonate to constant weight, specially prepared $CaCO_3$ and silica as ground quartz purified by heating with HCl.

OPTICAL PROPERTIES OF THE CRYSTALLINE PHASES.

The crystals obtained throughout the work were in nearly all cases very small and no precise measurements of optical properties were undertaken. It was necessary only to determine such properties as permitted the distinguishing of diopside from plagioclase.

The diopside occurred usually in stout crystals with prismatic elongation and strong birefringence. The plagioclases had a pronounced tabular development ‖ 010, the plates being often so thin that when viewed in plan (rhomb sections) their birefringence was barely discernible, whereas viewed on edge (needle sections) the birefringence was marked.

The refractive indices of the plagioclases were usually not very different from those of the glasses in which they were embedded, whereas the diopside indices were always conspicuously higher. In the mixtures rich in albite the crystals were always very minute and the indices of the plagioclase crystals were considerably higher than the glasses. The plagioclase crystals of these mixtures were, however, readily distinguished from diopside by their low extinction angles and negative elongation, whereas diopside has extinction angles up to 38° and those sections with low extinction have positive elongation.

TABLE I.

Composition		Temperature	Time	Result
Diopside	Anorthite			
80	20	1348	½ hr.	Glass and diopside
80	20	1352	½ hr.	Glass only
60	40	1275	½ hr.	Glass and diopside
60	40	1280	½ hr.	Glass only
60	40	1272	½ hr.	Glass and diopside
60	40	1268	½ hr.	Diopside and anorthite
50	50	1326	½ hr.	Anorthite and glass
50	50	1330	½ hr.	Glass only
50	50	1268	½ hr.	Diopside and anorthite
50	50	1272	½ hr.	Glass and anorthite
40	60	1388	½ hr.	Glass and anorthite
40	60	1392	½ hr.	Glass only
20	80	1483	½ hr.	Glass and anorthite
20	80	1487	½ hr.	Glass only

TABLE II.

Composition		Temperature		
Diopside	Albite		Time	Result
75	25	1337	1 hr.	Glass and diopside
75	25	1342	1 hr.	Glass only
50	50	1283	1 hr.	Glass and diopside
50	50	1287	1 hr.	Glass only
25	75	1208	1 hr.	Glass and diopside
25	75	1212	1 hr.	Glass only
10	90	1142	1 hr.	Glass and diopside
10	90	1147	1 hr.	Glass only

THE BINARY SYSTEMS.

It was necessary to study first the three binary systems: anorthite-albite, anorthite-diopside, and albite-diopside, and these results will be presented first.

Anorthite-Albite.

The system anorthite-albite had been studied formerly and, for details, reference can be made to the original paper.* The equilibrium diagram is reproduced in fig. 1.

Diopside-Anorthite.

The system diopside-anorthite is an ordinary eutectic system with the eutectic at 1270° and 42 per cent anorthite. The system is sufficiently described by presenting the equilibrium diagram fig. 2. The quenching determinations are given in Table I.

Diopside-Albite.

The diopside-albite system is also a eutectic system. It exhibits in emphasized form the location of the eutectic close to the low-melting component, being in this respect analogous to the silver-lead system among the metals. The equilibrium diagram is given in fig. 3 and the quenching determinations in Table II.

The liquidus of diopside was determined as far as 90 per cent albite but in mixtures richer in albite the high viscosity prevented the attainment of equilibrium. The position of the eutectic can, therefore, only be estimated by extrapolation of the liquidus, but it is clear that it must lie close to albite, probably at about 97 per cent albite. The temperature of the eutectic is not far below the melting-point of albite, probably at

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* N. L. Bowen, this Journal (4), xxxv, p. 577, 1913.

Fig. 1.

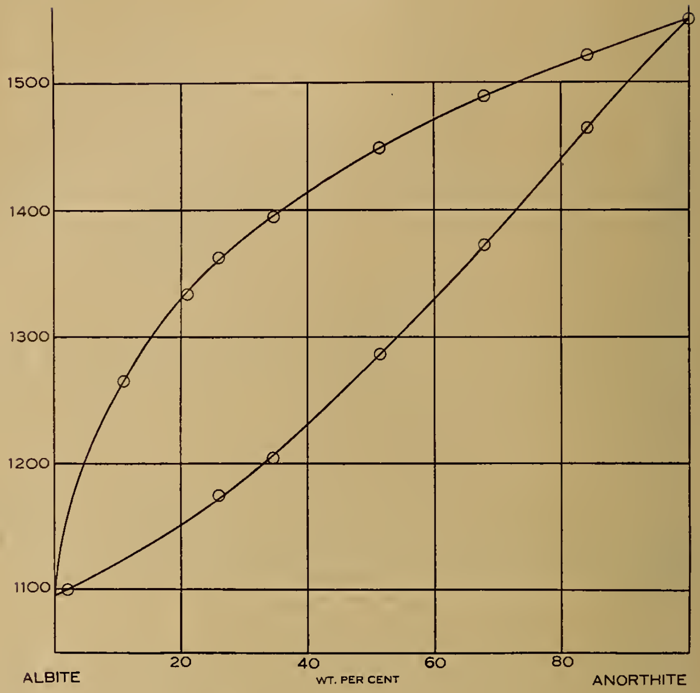
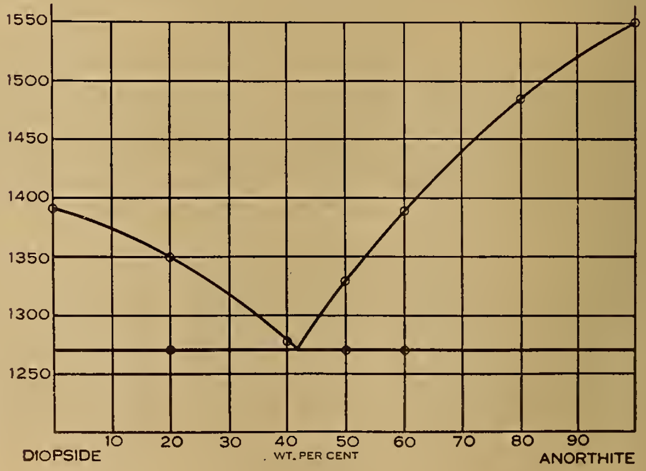
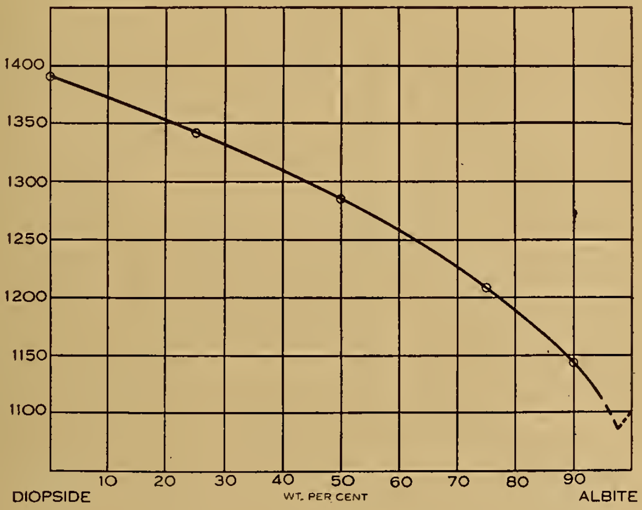

1500
1400
1300
1200
1100
20
40
60
80
ALBITE
WT. PER CENT
ANORTHITE

Fig. 2.


1550
1500
1450
1400
1350
1300
1250
10
20
30
40
50
60
70
80
90
DIOPSIDE
WT. PER CENT
ANORTHITE

about 1085°, at which temperature apparent traces of melting were found in a finely-ground mixture of crystalline diopside and Amelia County albite. This location of the eutectic does not depend entirely on extrapolation of the diopside liquidus, for it is confirmed by the shape of the fusion surface in the ternary system.

Fig. 3.



A rapid increase in the convexity of the diopside liquidus as it approaches albite is necessary in order to carry it below the melting point of albite. This increase has already begun at the last determined point (90 per cent albite) and is, theoretically, a general property of any liquidus as it approaches the other component.* We are accustomed to having the eutectic in a median position, so that the liquidus ends by meeting the other liquidus before passing into this region of increased curvature.

The Ternary System.

In the ternary system the expectation is that the composition triangle should be divided into two *fields*, one containing all

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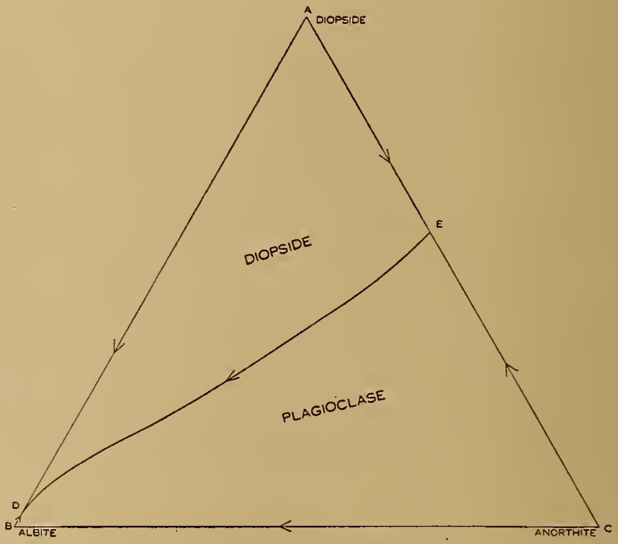
* See Roozeboom, Heterogene Gleichgewichte II, p. 275, fig. 103.

points representing the composition of liquids which can exist in equilibrium with plagioclase crystals, and the other all points indicating the composition of liquids which can exist in equilibrium with diopside. There should, presumably, be but a single *boundary curve* separating these fields and indicating the composition of all liquids which can exist in equilibrium with both plagioclase and diopside. This is the condition actually found and shown in fig. 4. Thus the field AED contains all points representing the composition of all liquids which can exist in equilibrium with (are saturated with) diopside and DECB is the corresponding field for plagioclase.

Fig. 4.



By means of isotherms we may indicate also the temperatures at which various liquids become just saturated with either solid phase (temperatures of beginning of crystallization), and this has been done in fig. 5. The quenching results on which the location of the isotherms and boundary curve rests are given in Table III.

Figure 5 may be regarded as a contoured map of a solid model showing fusion surfaces which represent the temperature of saturation (beginning of crystallization) for the various compositions, temperature being plotted vertically and composition horizontally on triangular coördinates. A vertical section of such a model along the direction of the boundary curve is shown in fig. 6.

Fig. 5.

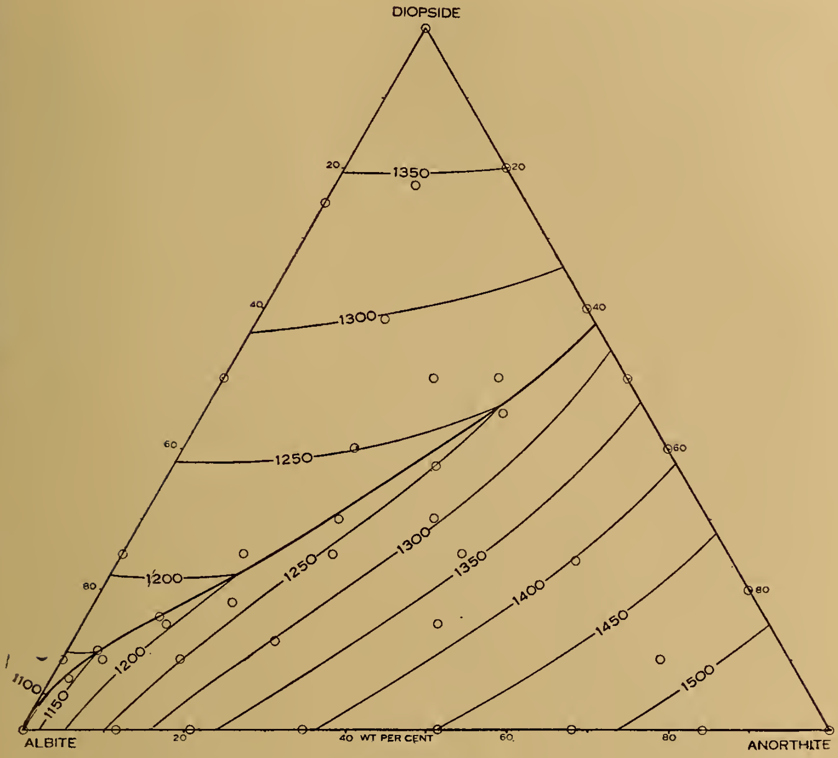


Fig. 5. Isotherms.

Fig. 6.

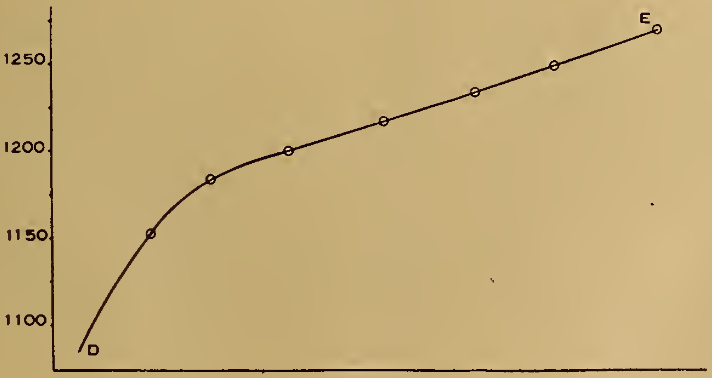


Fig. 6. Vertical section along boundary curve.

TABLE III.

Composition			Temperature	Time	Result
Anorthite	Albite	Diopside			
74	16	10	1484	½ hr.	Glass only
74	16	10	1479	½ hr.	Glass and plagioclase
56	20	24	1402	½ hr.	Glass and plagioclase
56	20	24	1405	½ hr.	Glass only
37	18	45	1255	1 hr.	Glass and plagioclase
37	18	45	1259	1 hr.	Glass only
34	16	50	1265	1 hr.	Glass and diopside
34	16	50	1269	1 hr.	Glass only
44	41	15	1372	½ hr.	Glass and plagioclase
44	41	15	1377	½ hr.	Glass only
42	33	25	1337	½ hr.	Glass and plagioclase
42	33	25	1341	½ hr.	Glass only
36	34	30	1296	1 hr.	Glass and plagioclase
36	34	30	1300	1 hr.	Glass only
32	30	38	1248	1 hr.	Glass and plagioclase
32	30	38	1253	1 hr.	Glass only
26	24	50	1273	1 hr.	Glass and diopside
26	24	50	1277	1 hr.	Glass only
10	12	78	1343	½ hr.	Glass and diopside
10	12	78	1347	½ hr.	Glass only
26	49	25	1256	1 hr.	Glass and plagioclase
26	49	25	1261	1 hr.	Glass only
24	46	30	1222	1 hr.	Glass and plagioclase
24	46	30	1226	1 hr.	Glass only
21	39	40	1250	1 hr.	Glass and diopside
21	39	40	1254	1 hr.	Glass only
16	25	59	1298	1 hr.	Glass and diopside
16	25	59	1302	1 hr.	Glass only
25	62	13	1303	1 hr.	Glass and plagioclase
25	62	13	1307	1 hr.	Glass only
17	65	18	1240	1 hr.	Glass and plagioclase
17	65	18	1244	1 hr.	Glass only
15	60	25	1208	1 hr.	Glass and diopside
15	60	25	1212	1 hr.	Glass only
14	76	10	1252	1 hr.	Glass and plagioclase
14	76	10	1255	1 hr.	Glass only
10	75	15	1197	1 hr.	Glass and plagioclase
10	75	15	1202	1 hr.	Glass only
9	75	16	1180	1 hr.	Glass, plagioclase and diopside
9	75	16	1183	1 hr.	Glass only
5	85	10	1175	1 hr.	Glass and plagioclase
5	85	10	1180	1 hr.	Glass only
4	85	11	1150	1 hr.	Glass, plagioclase and diopside
4	85	11	1155	1 hr.	Glass only

Three-Phase Boundaries.

In the simple system showing a ternary eutectic the location of the boundary curve and isotherms is sufficient to determine the crystallization of any mixture. The crystallization curves (curves indicating the change of composition of the liquid) are, within each field, straight lines radiating from the composition of the pure component (see fig. 7). The composition of the liquid passes along one of these straight lines until it meets a boundary curve and then follows the boundary curve to the ternary eutectic where crystallization is completed. On the other hand, in any system in which, on account of the existence of solid solution, there is no ternary eutectic the crystallization curves in the solid solution field are not straight lines, and there is no single temperature common to all mixtures at which crystallization is completed. Evidently, then, further determinations besides the locating of boundary curves and isotherms are necessary in the present system before the crystallization of individual mixtures can be described.

Fig. 7.

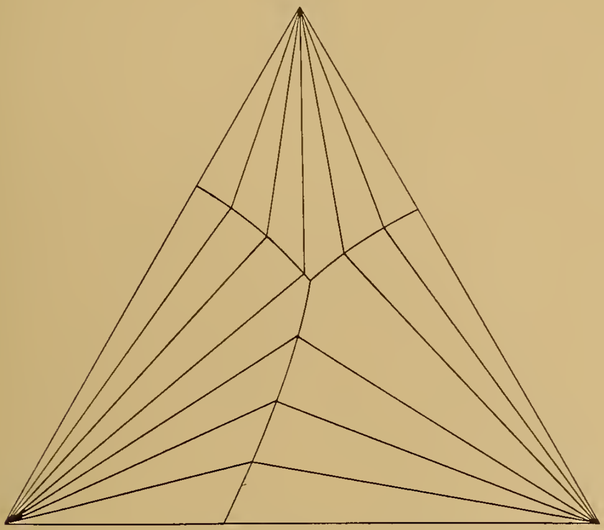


Fig. 7. Crystallization curves in a eutectic system.

Equilibrium in a eutectic system at a certain temperature T° may be represented graphically in fig. 8. DEF is the isotherm for T°. The phases present within the various areas are as follows:

area	DEF	all liquid
"	ADB	liquid D, solid A and solid B
"	DBE	liquid D — E and solid B
"	EBC	liquid E, solid B and solid C
"	EFC	liquid E — F and solid C
"	FAC	liquid F, solid C and solid A
"	FAD	liquid D — F and solid A

Fig. 8.

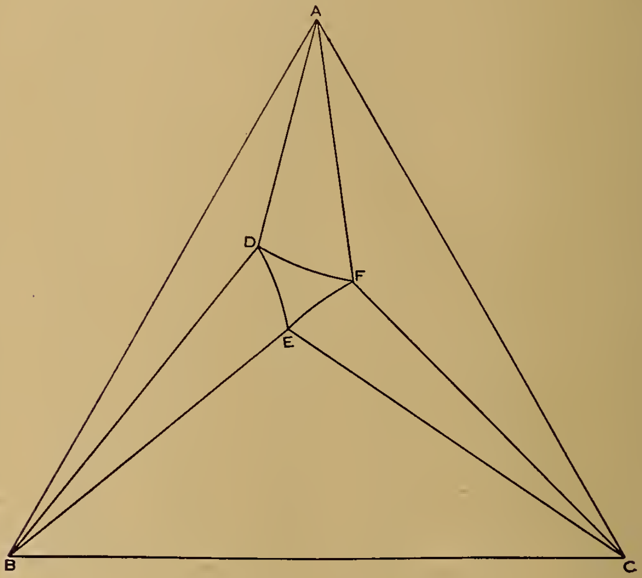


Fig. 8. Eutectic system at T°.

Evidently locating the isotherm DEF fixes all these relations since all the other lines are simply straight lines joining D, E and F with the corners of the triangle. In a system where solid solution occurs the matter is not so simple. Equilibrium at 1230° in the investigated system is shown in fig. 9 by means of full lines. DFE is the isotherm of 1230°. The phases present in the various areas are as follows :

area	DFEB	all liquid
"	EFG	liquid E — F and plagioclase K — G
"	ADF	liquid D — F and diopside
"	AFG	liquid F, plagioclase G and diopside
"	AGC	plagioclase G — C and diopside

The line FG which bounds the three-phase field AFG has been called a three-phase-boundary.* AF and AG likewise bound the three-phase field, but they are merely lines radiating from A, their position being completely determined by the points F and G. In order to be able to predict the phases present at 1230° in a given mixture it is obviously necessary to know the position of the line FG, the three-phase-boundary for that temperature, or at 1250° the line F′G′, and so on for other temperatures.

FIG. 9.

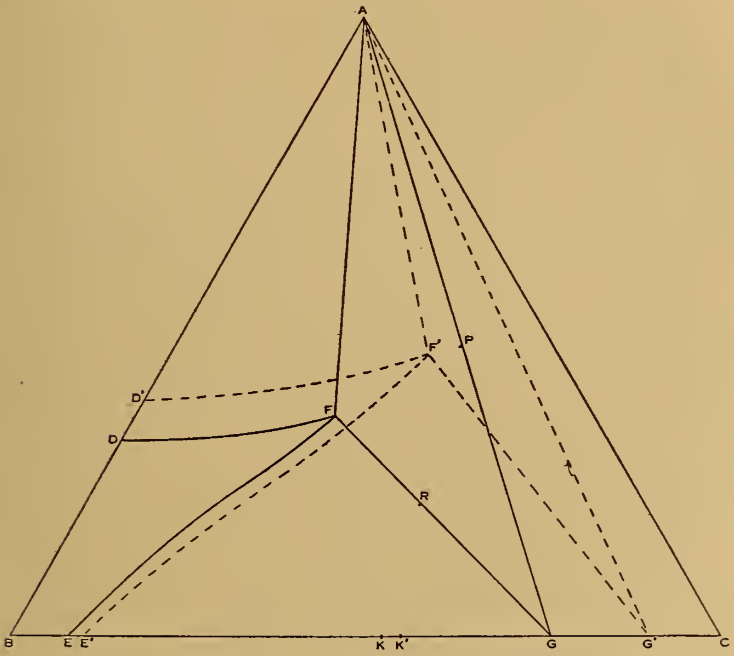


FIG. 9. Phase relations at 1230° (full lines) and 1250° (broken lines).

Determination of Three-Phase-Boundaries.

The determination of three-phase-boundaries can be accomplished in a number of ways the principles of which are readily understood by reference to fig. 9. For a given position of the isotherm DFE, i. e., a known temperature, it is only neces-

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* N. L. Bowen, The Ternary System : Diopside-Forsterite-Silica, this Journal (4), xxxviii, p. 222, 1914.

sary to note that G represents the composition of the plagioclase which at the temperature considered is in equilibrium with both diopside and liquid. If a mixture which gives all three phases is held at the desired temperature and the composition of the plagioclase is determined by optical methods, then the point G is determined and the figure for that temperature can be drawn. This may be called a composition method since it depends on the determination of the composition of the mix-crystal.

The three-phase-boundaries may be located by starting with a mixture of known composition and determining the temperature at which the three-phase area is entered either from above or below. Any point on the line AG, such as P, lies on the border of the three-phase area for 1230°, and at this temperature, as at all lower temperatures, it consists entirely of plagioclase and diopside, but if the temperature is raised very slightly the point enters the three-phase area for this higher temperature (note that the point P lies well within the three-phase area for 1250° AF′G′) i. e., liquid is added to the phases already present. A three-phase-boundary can, then, be located by determining the temperature of beginning of melting for any mixture. Thus if any mixture of diopside with plagioclase of composition G is taken and the temperature of beginning of melting is determined it will be found at 1230°. If the isotherm DFE for 1230° as previously determined is drawn then the join FG is the three-phase-boundary for 1230°.

We may determine three-phase-boundaries by entering the three-phase field from above. The point R lies within the field of plagioclase and liquid, E′F′G′ at 1250°, is on the border of the three-phase area for 1230°, and if the temperature is lowered a little it enters the three-phase area for this lower temperature, i. e., the liquid and plagioclase are joined by diopside. By determining the temperature (approached from above) at which plagioclase and liquid are joined by diopside in any mixture the three-phase-boundary passing through the point representing the composition of the mixture is thereby determined. Thus, if the mixture R is taken it is found that diopside first appears at 1230° and if the isotherm of 1230° DFE is drawn, FR joined and produced to G, then FG is the three-phase-boundary.

All three of these methods were applied to the determination of three-phase-boundaries.

Composition Method. — The composition method (first method) depends on the ability to determine the composition of the plagioclase crystals. These occur always as minute tabular crystals embedded in glass and their properties are very difficult to determine. In soda-rich mixtures the index of the plagioclase crystals is higher than that of the glass, in the lime-rich mixtures the reverse is true. In one intermediate mixture it was found that the index *a* of the crystals nearly matched that of the glass so that by measuring the index of the glass by the immersion method the composition of the plagioclase was determined. It was in this manner that the three-phase-boundary of 1250°, F′G′ of fig. 9, was located. At 1250° the liquid in equilibrium with both plagioclase and diopside, F′, has a refractive index as glass at room temperature of 1·572 and *a* of the plagioclase crystals nearly matches the glass, but is appreciably less (1·571), which places the composition of the plagioclase at Ab_1An_9(G′). This was the only case in which the composition method was applicable, for, when the indices of the crystals differ considerably from the containing glass, the crystals are too small for the determination of their refractive indices by direct comparison with immersion liquids.

Temperature Methods. — Determination of three-phase-boundaries by the method of finding the temperature of beginning of melting (second method) depends on the ability to detect the first trace of glass. This is a comparatively easy matter in a mixture otherwise homogeneous, so that the temperature of beginning of melting of plagioclase mix-crystals, say, can be accurately located. But in a mixture of plagioclase and diopside the first trace of glass is not easily detected and there would appear to be a tendency for this method to give a somewhat high result. Fortunately, however, this tendency is not very strong since the amount of glass increases very rapidly with a small rise of temperature for most compositions. (Note extent of flatter portion of boundary curve, fig. 6.)

Determination of three-phase-boundaries by this method was carried out by grinding together crystalline diopside and crystalline plagioclase of definite composition and determining the temperature at which the first liquid was formed. The results obtained are given in Table IV.

TABLE IV.

Mixture	Temperature of beginniug of melting
Ab_2An_1 + diopside	1176°
Ab_1An_1 + diopside	1200°
Ab_1An_2 + diopside	1219°
An_1An_5 + diopside	1240°

Determination of three-phase-boundaries by approaching the three-phase area from above (third method) was carried out with only two mixtures. In these plagioclase begins to separate from the liquid first and is later joined by diopside, the temperature at which diopside appears marking the border of the three-phase area. In Ab_1An_1 85 per cent–diopside 15 per cent, diopside first appears at 1216° ; in $Ab_{44}An_{56}$ 75 per cent–diopside 25 per cent, at 1230°.

Fig. 10.

Fig. 10. Three-phase-boundaries.

In fig. 10 the determined three-phase-boundaries are drawn in full lines and numbered according to the method of determination. In dotted lines the theoretical general direction of others is shown. A three-phase-boundary intermediate between two that are determined may be found by interpolation.

Crystallization of Mixtures in the Diopside Field.

Three-phase-boundaries being located, the course of crystallization (with perfect equilibrium) of any mixture whose composition is represented by a point in the diopside field can now be quantitatively described. Thus in fig. 11 the mixture F

(Ab_1An_1 50 per cent–diopside 50 per cent) begins to crystallize at 1275°, diopside separating and the liquid changing along the straight line AFG towards G. At 1235°, when the liquid has the composition G, plagioclase of composition H (Ab_1An_4) begins to crystallize, the point H being determined by the three-phase-boundary (GH) through G. As the temperature is lowered the composition of the liquid follows the boundary curve towards M. At 1218°, when the liquid has the composition K, the plagioclase has changed in composition from H(Ab_1An_4) to L(Ab_1An_2). Finally at 1200° the liquid is used up, the last minute quantity having the composition M, the plagioclase having now changed in composition to Ab_1An_1(Z). MZ is the three-phase-boundary through the composition Ab_1An_1 and fixes at the point M the temperature of final consolidation of F or of any other mixture of Ab_1An_1 and diopside.

Fig. 11.

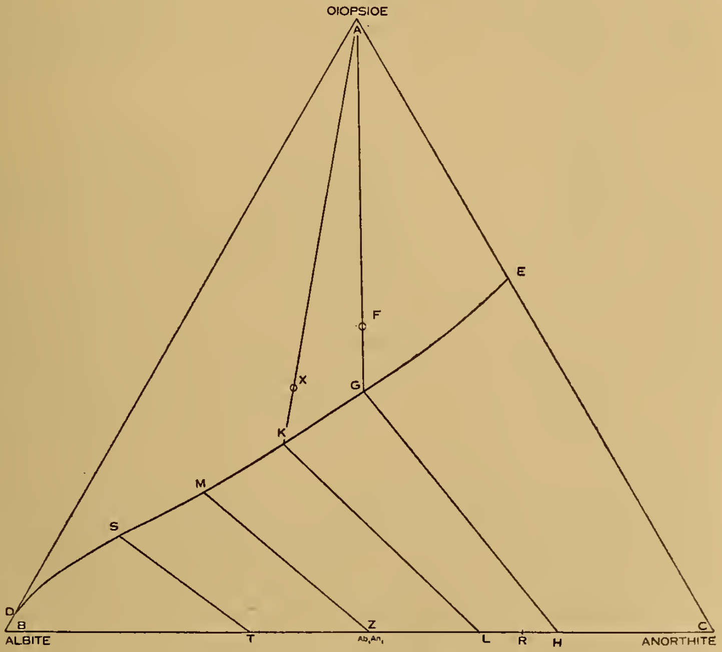

Fig. 11. Crystallization of mixtures in diopside field.

The mixture X(Ab_2An_1 60 per cent–diopside 40 per cent) begins to crystallize at 1252° with the separation of diopside, and the liquid changes along the straight line AXK. At 1218°, when the liquid has the composition K, plagioclase of composition L(Ab_1An_2) begins to crystallize, KL being a three-phase-boundary. On further lowering of temperature the composition of the liquid moves along the boundary curve towards S, plagioclase increases in amount and changes continually in composition, diopside also increases in amount, until at 1176° the liquid is finally used up. The last of the liquid has the composition S and the feldspar has changed in composition to T, ST being a three-phase-boundary.

These examples make clear the necessity of determining three-phase-boundaries in order that the composition of plagioclase at any temperature may be known.

Crystallization of Mixtures in the Plagioclase Field.

For all mixtures in the diopside field the change of composition of the liquid until the boundary curve is attained is represented by a straight line. (Note AFG and AXK.)

For all mixtures in the plagioclase field, however, the liquid follows a curved course in reaching the boundary curve. The crystallization of any of these mixtures can not, therefore, be quantitatively described unless these crystallization curves in the plagioclase field are determined, and for this reason these curves were determined for two representative mixtures. Though applied to only two mixtures the method may perhaps prove useful in other more or less similar investigations and will therefore be described in full.

Determination of the Composition of Liquid and of Mix-crystals in a Two-Phase Mixture.—In order to find the composition of liquid in equilibrium with crystals at any temperature in a binary mixture, it is necessary only to hold a mixture at the desired temperature, quench it and determine the refractive index of the glass.* In a ternary mixture, however, the measurement of the refractive index of the glass is not sufficient to fix its composition. The composition can, nevertheless, be located as lying on the curve joining the composition of all glasses having that measured refractive index. Such curves will be referred to as isofracts.† But it is known also that the composition of the liquid must lie on the isotherm of the temperature at which the liquid was held. It must, therefore, lie at the point of intersection of the isofract and the

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* N. L. Bowen: The Melting Phenomena of the Plagioclase Feldspars, this Journal (4), xxxv, p. 585, 1913.

† Objection to this term, based on its mixed derivation, seems to me to be outweighed by the fact that the prefix *iso* is that commonly accepted in this sense and therefore preferable to, say, *equi* while *fract* is mnemonic of refractive index.

isotherm. In order to apply this method, then, it is necessary to determine isotherms and isofracts, to hold the desired mixture at a measured temperature, quench and determine the refractive index of the glass. The point of intersection of the isotherm of the measured temperature and the isofract of the determined refractive index represents the composition of the liquid.

TABLE V.

Composition of glass		
Diopside	Plagioclase	Refractive Index
100	0	1·607
50	50 Ab	1·548
0	100 Ab	1·489
17·5	82·5 Ab_4An_1	1·523
60	40 Ab_2An_1	1·571
40	60 Ab_2An_1	1·553
25	75 Ab_2An_1	1·539
0	100 Ab_2An_1	1·517
50	50 Ab_1An_1	1·569
30	70 Ab_1An_1	1·553
0	100 Ab_1An_1	1·531
45	55 Ab_1An_2	1·573
25	75 Ab_1An_2	1·560
0	100 Ab_1An_2	1·545
60	40 An	1·594
0	100 An	1·575

The measurements of refractive indices, on which the location of isofracts is based, are given in Table V and the isofracts are drawn in fig. 12. The refractive indices were determined on glasses of known composition, the glass being compared with immersion liquids until a liquid whose index matched the glass was obtained. The index of the liquid was then determined on the refractometer. The probable error is usually not more than ·001 but an error of ·002 is possible in some cases.

If the mixture Ab_1An_1 85 per cent–diopside 15 per cent (D) is held at 1300° and quenched, the refractive index of the glass is found to be 1·539. Its composition is therefore fixed at the point P, fig. 12. The mixture, $Ab_{18}An_{82}$ 90 per cent–diopside 10 per cent (E), held at 1400° gives a glass of refractive index 1·561, the composition being, therefore, that of the point R, fig. 12.

It is important to note also that this determination of the composition of the liquid fixes the composition of the plagioclase crystals at the same time. Thus the composition of the crystals in the former case is given by joining PD and producing it to G which represents the composition of the plagioclase crystals. Similarly the point K on the straight line REK represents the composition of the plagioclase in the latter case. This method is the only one applicable to the determination of the composition of the plagioclase crystals in equilibrium with any liquid in the plagioclase field (i. e., not on the boundary curve, in which case the three-phase-boundaries fix the composition of the plagioclase) for the crystals themselves are too small for precise optical determination.

Fig. 12.

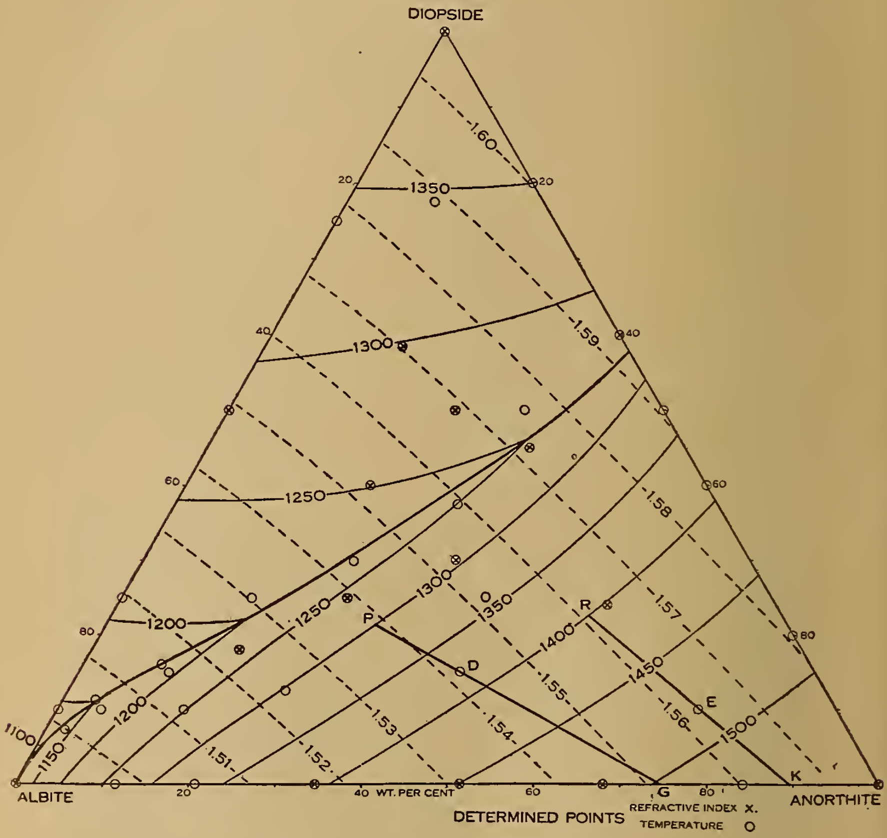

Fig. 12. Isotherms and isofracts.

Crystallization Curves in the Plagioclase Field.—With the aid of the foregoing determinations of the composition of the liquid two representative crystallization curves in the plagioclase field can be drawn and the crystallization of the mixtures discussed. The mixture, Ab_1An_1 85 per cent–diopside 15 per cent (D, fig. 13), begins to crystallize at 1375° with the separation of plagioclase of composition Ab_1An_4. As the temperature falls the plagioclase increases in amount and changes in composition until at 1300° the liquid has the composition P and plagioclase the composition Ab_1An_3 (G of fig. 12). When the temperature has fallen to 1216° diopside begins to crystallize, the liquid then having the composition M (fig. 13) and plagioclase the composition S (Ab_1An_2), SM being the three-phase-boundary through D. With further lowering of temperature the liquid follows the boundary curve, both diopside and plagioclase crystallizing, and at 1200° the liquid is all used up. The composition of the plagioclase is now Ab_1An_1 (F), FH being a three-phase-boundary.

FIG. 13.

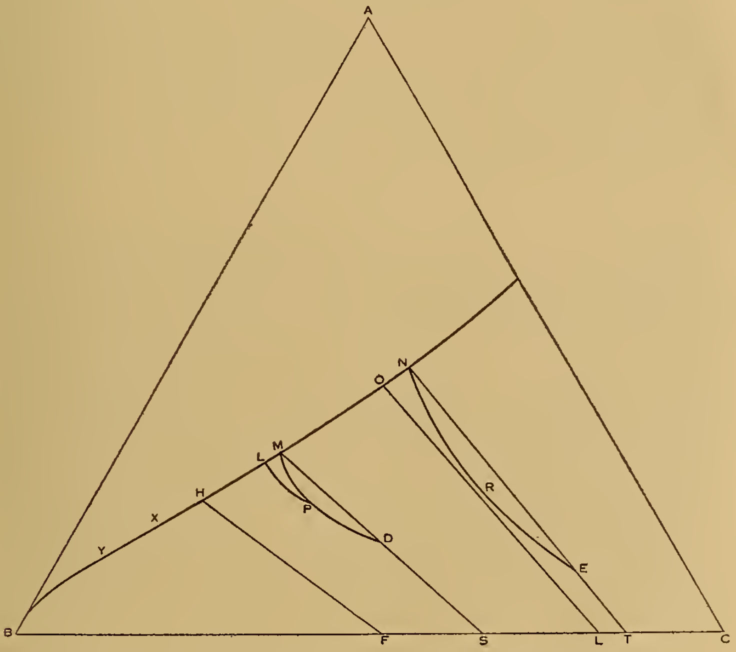

FIG. 13. Crystallization of mixtures in the plagioclase field.

In the case of the liquid E ($Ab_{18}An_{82}$ 90 per cent – diopside 10 per cent) crystallization begins at 1480° with the separation of Ab_5An_{95} and the composition of the liquid follows the curve ERN. At 1245° diopside begins to crystallize. The composition of the plagioclase is now T ($Ab_{15}An_{85}$), NT being a three-phase-boundary. As the temperature is lowered both plagioclase and diopside crystallize until at 1237° all the liquid is used up. The composition of the final liquid is O and the feldspar has attained the composition L ($Ab_{18}An_{82}$.)

It should be noted that the crystallization curves DPM and ERN apply to the liquids D and E respectively and to no other liquids. Thus the crystallization curve of the liquid P is not the curve PM but the new curve PL, i. e., if we start with a liquid P free from crystals the composition of the liquid follows the course PL. Only when the liquid P contains in it the crystals formed during the change from D to P does the further course of the liquid coincide with PM. Moreover, the liquid P when originally free from crystals becomes on cooling completely crystalline, not at 1200° (H), as before, but at a somewhat lower temperature.

Crystallization with Zoning.

Throughout the foregoing discussion of crystallization perfect equilibrium is assumed. The conditions are supposed to be such that crystals of plagioclase can change their composition through and through in response to the demands of equilibrium. It may be considered, however, that crystallization takes place in a quite different manner. When plagioclase of a certain composition has separated it may remain as such and become surrounded by layers of different composition deposited by the continually changing liquid. The liquid is in equilibrium at any instant only with the material crystallizing at that instant and not with crystals already formed.* A plagioclase crystal, once separated, does not participate further in the equilibria. As far as any effect on the course followed by the liquid is concerned the crystal may be considered absent. The course of crystallization of the liquid P, fig. 13, in the absence of crystals has been compared in the foregoing with that followed in the presence of crystals. If we examine also the liquid M, say, we find that if it crystallizes in the presence of crystals formed during the change in composition of the liquid from D to M, it then becomes completely crystalline at 1200° and the final liquid has the composition H. On the other hand, if the crystals referred to are separated from the liquid M complete crystallization does not take place until the temperature 1170° is attained and the final liquid has the composition X, i. e., is very much richer in albite. If in this latter case a second removal of crystals took place when the liquid

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* This corresponds with "Erstarrung erster Art" of Schreinemakers, Zs. phys. Chemie, 1, p. 189, 1905.

had the composition H complete crystallization would not then take place until the temperature had fallen to 1125° and the final liquid has then the composition Y, exceedingly rich in albite.

If this separation of early crystals from liquid is a continuous process accomplished through zoning of the crystals, it is clear that this continual lowering of the temperature of final consolidation and offsetting in the composition of the liquid is limited only by the eutectic albite-diopside, 1085° and 97 per cent albite. There is a certain theoretical rate of cooling which will give maximal zoning, in which case this limiting temperature and composition of the liquid will be actually attained. An increased rate of cooling will bring about undercooling, and crystallization will be completed when the liquid has the composition Y or X or H, or with very rapid cooling, the liquid M may be cooled below 1170° before crystallization begins, in which case it will crystallize *in toto* without any offsetting of composition. A rate of cooling slower than that which gives maximal zoning will also limit the offsetting in the composition of the liquid on account of a certain amount of adjustment between liquid and crystals. The result is that the final liquid may be Y or X, or with exceedingly slow cooling (perfect equilibrium) H.

However, even when the cooling is slow enough to permit perfect equilibrium other factors may intervene to produce the same offsetting in the composition of the liquid as does zoning. These are the separation of crystals from the liquid, or from some of the liquid, by their sinking or by a squeezing-out or draining-off of residual liquid. Clearly the opportunity for both of these, especially the former, increases with slow cooling. The rate of cooling of any liquid of the present system is, therefore, of fundamental importance in determining the range of composition which will be covered by the liquid as it changes during crystallization, and likewise the range of composition of the crystalline products.

The Significance of the Results in Petrologic Problems.

The aim of experimental investigations of silicate melts is, of course, the explanation of some of the multitudinous, more or less disconnected facts concerning igneous rocks that have accumulated with the advance of descriptive petrography. It still is, and possibly always will be, a considerable extrapolation from the simple systems that can be investigated quantitatively to the more complex systems, or perhaps rather system, represented by magmas. Nevertheless, considerable progress is being made in the shortening of this extrapolation. It is not long since the discussion of the theory of the crystallization of igneous rocks was carried out by describing the crystallization of some simple binary eutectic mixture such as salt and water, and winding up with the statement that the crystallization of igneous rocks is in some measure analogous. A better grasp of the theoretical aspects of the problems and a considerable number of exact investigations of silicate melts themselves have now carried the matter well beyond this stage.

In the present investigation the mixtures treated are sufficiently close to certain natural magmas, in essential mineral composition, that I have, with more or less propriety, referred to them as haplobasaltic, haplodioritic and related magmas. (Note also analyses compared in Table VI.) The names seem further justified by the number of facts and principles governing the crystallization of their natural analogues that are brought out by the investigation of these artificial melts.

One fact stands out very clearly, viz., the great difference between the crystallization of the mixtures that have been described and crystallization in a system with a ternary eutectic. *There is no eutectic between diopside and any intermediate plagioclase, still less between plagioclase and a complex pyroxene solid solution such as augite.*

There is, then, nothing to be gained from the search for the gabbroic eutectic, the dioritic eutectic and so forth. Appreciation of the non-existence of such eutectics is an important matter. The existence of a gabbro eutectic would mean that there is a certain definite, lowest-melting mixture of calcic plagioclase and augite, with a little magnetite, towards which the liquid, during the crystallization of any gabbro, always proceeds and *beyond which it can not pass.* The sinking of crystals or the squeezing-out of residual liquid would avail nothing in enabling the liquid to pass the eutectic temperature and composition, the eutectic being a *necessary end-point.* A gabbro magma might give rise locally to anorthosite and pyroxenite by the sorting of crystals according to their densities, but, by crystallization-differentiation, it could never give diorite or syenite or granite.

On the other hand, if it is realized that the crystallization of gabbro is in large measure analogous to that of haplogabbro the possibility of the derivation of an igneous rock series becomes apparent. Haplogabbro magma of composition Ab_1An_2 50 per cent–diopside 50 per cent, may, if it is cooled very rapidly, give rise simply to haplogabbro with 50 per cent plagioclase crystals of the uniform composition Ab_1An_2 and 50 per cent diopside. Yet if the same original magma is cooled more slowly, different results may be obtained.* The plagioclase crystals may be zoned, with compositions ranging

* See discussion of figures 11 and 13.

from Ab_1An_3 to Ab_2An_1 and, if it had happened that the liquid was separated from the crystals before the later zones of plagioclase were formed, this liquid would, of course, have crystallized to a body of haplodiorite. Again, this separated haplodiorite magma might have crystallized under conditions which produced a zoning of its plagioclases, ranging, say, from Ab_1An_1 to Ab_4An_1, and if the liquid were separated at a late stage it could give a body of haplosyenite.

If sinking of crystals took place as they grew in the liquid it is plain that the effect on the uppermost liquid would be of the same kind, indeed only stirring of considerable vigor could prevent the formation of haplosyenite as the upper differentiate of a large, slowly-cooled mass of haplobasaltic magma. The only limit beyond which this differentiation could not pass is a mixture of 97 per cent albite and 3 per cent diopside.

Another feature of these differentiates is worthy of note, viz., the fact that as the plagioclase becomes more alkalic the percentage of diopside (colored constituent)* decreases rapidly. Thus in the original haplogabbro there was 50 per cent diopside, in haplodiorite derived in the manner outlined about 30 per cent, in haplosyenite 10–15 per cent. On the other hand, if it is imagined that these latter types were not derived by this process of development from more basic types but were, say, specially created, then there would be no necessary relation between the alkalinity of the plagioclase and the proportion of diopside.

The crystallization of the natural analogues of these melts, gabbro, diorite, etc., is beyond doubt a considerably more complex process, nevertheless the plagioclase mix-crystal series must exert a similar influence, and when we turn to the rocks this influence is plain in what is commonly termed the subalkaline series. The increasing alkalinity of the feldspar and the accompanying decreasing importance of the colored constituents in the later members (members of latest consolidation) of this series is a well-attested fact. One important difference between the artificial melts here described and the natural series is the prevalence of free silica as quartz in the later members. In another paper this matter will be discussed in some detail and it will be shown that the formation of olivine at an early stage and the later formation of hornblende and especially of biotite in the presence of water account satisfactorily for the development of quartz.

The natural series presents a further important difference from the 'haplo' series in that there is no special mixture, analogous to that containing 97 per cent albite and 3 per cent diopside, which can be referred to as a necessary end, unless

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* I. e., corresponding to a colored constituent as these terms are ordinarily used though the pure, artificial diopside of these mixtures is not colored.

this is some frozen aqueous solution. The presence of volatile components and the existence of various equilibria between them and silicates removes the necessity for the existence of an end-point similar to that in the 'haplo' series.

There appears then to be no room for reasonable doubt that the differentiation of the sub-alkaline series of igneous rocks is controlled entirely by crystallization. Moreover, the systematic decrease in the amount of colored constituent with increasing alkalinity of the feldspar indicates that the more acid types are not original magmas,* for in this case there would be no reason for such a balance in the proportion of these contrasted constituents, whereas this finds a natural explanation if the more acid magmas are regarded as derived from basic material, being, as it were, successive mother liquors from the crystallization of the basic magmas.

In this connection it seems worth while to point out the considerable degree of similarity in composition (when the absence of iron and potash and the fact that other constituents, principally lime, must make up this shortage are taken into account) between a haplodiorite magma from the investigated system and the average diorite as computed by Daly (Table VI). This haplodiorite is not any random one but is one which could be deprived as a mother liquor from the crystallization of haplobasaltic magma.† The similarity is suggestive in connection with the idea that diorites are related to basaltic magma in the same way.

J. H. L. Vogt believes that differentiation is accomplished in the liquid state,‡ but when he proceeds to discuss the problem he bases the discussion entirely on the progress of *crystallization.* Indeed, Vogt's paper, though professedly the opposite, is one of the best essays we have in favor of crystallization-differentiation.

TABLE VI.

	I	*mols.*	II	*mols.*
SiO_2	57·56		57·8	
TiO_2	·85		--	
Al_2O_3	16·90		17·0	
Fe_2O_3	3·20		--	
FeO	4·46		--	
MgO	4·23		6·5	
CaO	6·83		14·0	
Na_2O	3·44	·077	4·7	·076
K_2O	2·15		--	

I Average diorite as calculated by Daly.
II A haplodiorite represented by a point on the boundary curve.

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* In the sense that they always existed as such.

† I. e., it lies on the boundary line.

‡ Uber anchi-monomineralische und anchi-eutectische Eruptivgesteine. Videnskabs-Selsk. Skr. I., Math. Naturv. Kl. 1908, No. 10.

Summary.

Mixtures of diopside with various members of the plagioclase series, referred to as haplobasaltic,* haplodioritic and so forth, according to the nature of the plagioclase, are studied by the quenching method of thermal analysis. Equilibrium, determined in this manner, is represented graphically in several diagrams. All the determinations which are necessary for the complete description of the crystallization of any mixture have been made and are presented.

The facts determined for haplodiorite and so forth are applied to their natural analogues and it is shown that there can be little reason to doubt that crystallization controls the differentiation of the subalkaline series of igneous rocks.

Geophysical Laboratory of the Carnegie Institution of Washington.

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* From the Greek ἁπλόος = simple.

Art. XVII.—*The Migrations and Geographic Distribution of the Fossil Amphibia*; by Roy L. Moodie.

The evidence which is at present available points to the origin of the Amphibia in North America, some time during the late Siluric or early Devonic, possibly within the Devonian entirely. The group is represented as continuing in North America until well along in the Cretaceous, when evidences of the forms are lacking. There can be but little doubt, however, that the Caudata and Salientia existed in North America somewhere in post-Jurassic times, but evidences of their habitat are wanting until the Pliocene and the upper Pleistocene, when they have been reported from Kansas, Arkansas and Texas.

The Amphibia early migrated from North America across the Atlantic by way of some hypothetical route to Europe, where the group is represented certainly in the Lower Carboniferous of Gilmerton, Scotland, by *Pholidogaster pisciformis* as described by Huxley. The abundant remains in the Upper Carboniferous and Lower Permian of Ireland, England, France, Saxony, Bohemia and surrounding regions, testifies to the vigor of the migrants and their ability to establish themselves among strange conditions. The environmental conditions were, however, similar if not identical to those among which their congeners lived in North America. The problem of the early migration of such slow-moving forms as the Amphibia such vast distances as exist between Illinois, Ohio and Pennsylvania and the western shores of Europe is a difficult one to solve, and so far we know nothing of the paths of migration of these small creatures. It is possible for us to imagine a series of lagoons and swamps extending across the North Atlantic land bridge by means of which these animals could, through many eons of time, arrive at the regions in which they have left their remains.

It has been suggested elsewhere* that the earliest forms might have developed from the same or similar piscian ancestors, but this seems incredible in view of the close relationship existing between the Branchiosauria of Saxony and those of the Mazon Creek beds where the genera are closely related and all belong to the family Branchiosauridæ. It is a matter of great interest that the Amphibia developed along parallel lines in Europe, Asia and North America throughout all post-Paleozoic time. The same orders, with the exception of the Apoda, occur in the various continents.

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* Journ. Geol., xvii, p. 39, 1909.

During the Triassic the Amphibia, as represented by the Stereospondylia, attained their widest distribution in pre-Pleistocene times, when they are known from all continents of the globe excepting South America, even occurring as far north as Spitzbergen and as far south as Cape Colony and Australia. The group then went utterly out of existence from some cause which it is impossible for us to ascertain, unless it be due to some weakening of constitution owing to extreme specialization.

The abrupt appearance of the frogs in the Jurassic of Spain and England and in the Comanchean of North America is a matter of great interest and would seem to indicate a long antecedent history. The history of the modern Salientia and Caudata is recorded in an almost unbroken series of discoveries in Europe, but, so far as I have been able to ascertain, the groups are not definitely known from North America until the Pleistocene. It is quite possible that during the late Pliocene or early Pleistocene forms migrated from North America to South America, where, in the Pleistocene caves of Brazil, we find the first traces of South American Amphibia in the genus *Leptodactylus*, which, as far as we know, is characteristic of that continent.

The Apoda are wholly unknown in geologic history, and we now know them widely distributed as indicated by the accompanying "Table of Geologic and Geographic Distribution of Amphibia."

The information we have of the Amphibia is very incomplete and an attempt has been made to record the information we have in as compact a form as possible. The distribution of the Amphibia, as indicated by the remains which have been recovered, is very puzzling, in that in Europe, Asia and South America occur forms of Salientia which are so characteristic of the various continents. In Asia in the Eocene occurs a representative of the genus *Oxyglossus*, and the genus is still represented in the Oriental region by three species of the same and closely allied genera. South America is remarkable in being the home of the genus *Leptodactylus*, which reached that continent in Pleistocene times, and is now found in Australia and the whole of Central and South America. Europe has the same kind of distribution as indicated by the salientian family Paleobatrachidæ from the Miocene, which according to Wolterstorff* is allied, on the one hand to the Pelobatidæ and on the other to the Xenopodidæ, the former of which families is now largely restricted to the Oriental region while the latter is typical of the Ethiopian realm. The solution of this distribution would seem to lie in that the various forms had, in the

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* Jahrb. nat. Ver. Magdeburg for 1886, p. 156.

FIG. 1.

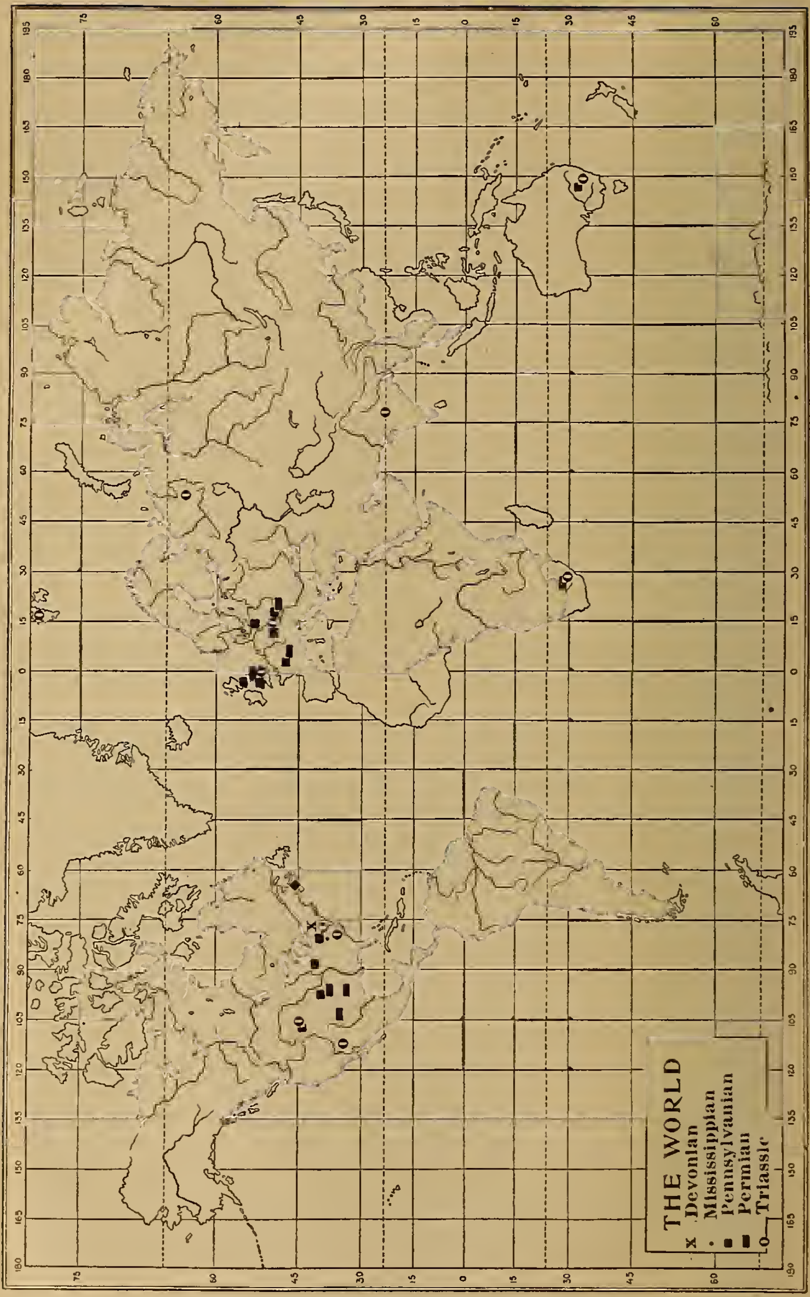

FIG. 1. A map showing the distribution of the Amphibia in pre-Jurassic times as their distribution has been thus far recorded by discoveries of fossil remains.

several regions, a long history of which we now have no record. We see only the culminations of a long line of descent.

The Stereospondylia without doubt arose in North America in the Carboniferous, for we have early indications of the group on this continent represented by the genera *Eosaurus*, *Baphetes*, *Eobaphetes*, and possibly the Macrerpetidæ and unnamed fragments from the Coal Measures of Ohio and Nova Scotia. The group is apparently unknown in the Permian, but representatives of the group occur in the Upper Triassic of Wyoming. Members of the stereospondylous Amphibia are, as stated above, the most cosmopolitan of the pre-Pleistocene Amphibia.

The distribution of the Branchiosauria and the Caudata is interesting to study and seems to confirm the contention that the branchiosaurs are the ancestral forms of the salamanders. They are known only from North America and Europe, apparently not migrating either to Asia, Africa or South America until relatively late in Tertiary times; reaching Asia possibly in the Pliocene, for we find the European Miocene *Megalobatrachus* (*Cryptobranchus*, *Andrias scheuchzeri*) well established in Japan, in the Island of Nippon, where Th. von Siebold in 1829 secured from the fish markets the earliest known representative of this interesting salamander. This distribution indicates that the creatures had migrated across Eurasia before the subsidence of the basin of the Japan Sea in pre-Pleistocene times, or at least before the Strait of Korea was formed. The Branchiosauria without doubt arose in North America, at least we find in this continent the oldest representatives of the order.

The Temnospondylia are first known from the Mazon Creek beds and at a very slightly later geological period from the Coal Measures of Bohemia. From Europe the group migrated to the Oriental and Ethiopian regions in Upper Permian or Lower Triassic times. Whether the group gave rise to any of the numerous orders of reptiles, as has been suggested, is still uncertain.

A summary of the foregoing discussion will be found in the accompanying table, and is graphically represented in the accompanying map.

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TABLE OF GEOLOGIC AND GEOGRAPHIC DISTRIBUTION OF AMPHIBIA.

Geologic Periods	North America	South America	Europe	Asia	Africa	Australia
Cambrian						
Ordovician						
Silurian						
Devonian	Footprint—Thinopus antiquus					
Mississippian	Footprints in Virginia and Pa.		? Pholidogaster			
Pennsylvanian	Branchiosauria Caudata Salientia (?) Microsauria Stereospondylia Temnospondylia Diplocaulia		Branchiosauria Microsauria Temnospondylia			
Permian	Diplocaulia Temnospondylia Caudata		Branchiosauria Microsauria Temnospondylia	Temnospondylia	Temnospondylia	
Triassic	Stereospondylia		Stereospondylia	Stereospondylia	Stereospondylia	Stereospondylia
Jurassic			Salientia			
Comanchic	Salientia		Caudata			
Cretaceous	Caudata					
Eocene				Salientia		
Oligocene			Salientia			
Miocene			Caudata Salientia			
Pliocene	Salientia					
Pleistocene	Caudata Salientia	Salientia	Caudata Salientia	Salientia		
Recent	Apoda Caudata Salientia	Apoda Caudata Salientia	Caudata Salientia	Apoda Caudata Salientia	Apoda Caudata Salientia	Salientia

Art. XVIII.—*The Microscopical Characters of Volcanic Tuffs—a Study for Students*; by L. V. Pirsson.

The recognition of fragmental volcanic material in fresh surficial deposits is usually relatively easy, both from characters which may be observed in the field and in thin section under the microscope. In proportion, however, as such deposits become altered increasing difficulties are met with and where they have been buried under later sediments, and in many cases metamorphosed to a greater or lesser degree, the task of determining them becomes one of the most arduous which confronts the petrographer. Every point of vantage yielded by field studies, the megascopic structure, thin section, and chemical analysis, must be made use of.

Moreover, the difficulty may be increased in another way. In the case where we have to determine whether a given rock is igneous or sedimentary; whether it has been formed by the solidification of a fluid magma or not; there is no transitional stage between them to consider. This is not the case with volcanic tuffs; they may fall on the land and show little or no evidence of bedding; they may fall into water and exhibit it in marked perfection. While falling into water they may be mingled with contemporaneously deposited land-waste brought by currents or streams; or, if fallen originally upon the land, after more or less oxidation, or none, depending on the length of their sojourn, they may be washed down into seas or lakes and mingled in the process with greater or lesser quantities of the ordinary products of land erosion. Thus every degree of perfection of stratification in pure tuffs may be expected, and every degree of transition into ordinary sediments—sandstones, and shales. The intermingling may be by pure layers of each, bed after bed, of any degree of thinness; or of grains of the different materials in the same bed.

It has seemed to the writer that in the various text-books on petrology the subject of volcanic tuff deposits has never been as adequately or systematically treated as it should be. In some works, especially the briefer ones, they are considered in such a general way that the student in search of information receives very little idea of the characteristics necessary for his guidance in their determination. In the more comprehensive hand-books, on the other hand, there is so much detail given, especially of local occurrences, that the student fails to obtain that comprehensive view of essentials which should form the basis of his knowledge. There are a number of excellent essays by investigators in the literature on particular occurrences, one of the best of which is on the so-called "Lenneporphyries" by Mügge,[*] with admirable plates, but these are not always accessible to the student, neither are they written in a form convenient for his use.

The writer during the past twenty odd years has had occasion to study tuffs in a number of cases in his own researches on particular areas,[†] and in supervising the work of students in his laboratory who were engaged in research on material collected in the preparation of their theses for the doctor's degree, he has had opportunity for the study of many more.[‡] Sometimes the material under investigation was fresh distinct volcanic ash or tuff, but it has often been a question to be decided, if possible, whether certain older, more or less altered, interbedded rocks were volcanic tuffs or not. In the latter case it has then been necessary to start from the unaltered typical varieties and trace the various gradations into those which have been changed. During the course of this experience much has been learned, the details of which are not given in the various publications cited; only the final decisions arrived at. It has been thought, therefore, that a succinct account of some of these observations combined with the results of other petrologists would be of interest and value to students of petrology; more especially since the sedimentary rocks are

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[*] Untersuchungen ueber die "Lenneporphyre" in Westfalen und den angrenzenden Gebieten," O. Mügge, Neues. Jahrb. für Min., B. B. viii, p. 533–721, 1893.

[†] Castle Mountain Mining District, Bull. 139, U S. G. S. 1896, pp. 73, 78, 127; Judith Mts., Mont., 18th Ann. Rep., U. S. G. S., Pt. III, 1898, p. 482; Igneous Rocks of the Highwood Mts., Bull. 237, 1905, pp. 56, 158.

[‡] H. E. Gregory: Contributions to Geology of Maine, Pt. II, Bull. 165, U. S. Geol. Surv., 1911, pp. 120–131.

Jos. Barrell: Geology and Ore-deposits of the Elkhorn Mining Dist., Mont., 22d Ann. Rep. U. S. Geol. Surv., Part II, 1902, p. 523.

F. D. Laney: Gold Hill Mining Dist., Bull. 21, North Carolina Geol. Surv., 1910. pp. 29–37.

J. E. Pogue, Jr.: Cid Mining Dist., Bull. 22, North Carolina Geol. Surv., 1910, p. 43 et seq,

D. D. Cairnes: Wheaton Dist., Yukon Terr., Mem. 31, Geol. Surv. Canada, 1912, pp. 61–69.

G. F. Loughlin: Gabbros and Associated Rocks at Preston, Conn., Bull. 492, U. S. Geol. Surv., 1912, p. 67.

H. H. Robinson: San Franciscan Volcanic Field, Ariz., Prof. Paper 76, U. S. Geol. Surv., 1913.

R. D. Crawford: Geol. and Ore-deposits of Monarch and Tomichi Dists., Col., Colo. Geol. Surv., Bull. 4, 1913, p. 175.

M. E. Wilson: Kewagama Lake Map-Area, Quebec, Geol. Surv. Canada, Mem. 39, 1913, p. 45.

M. Y. Williams: Arisaig-Antigonish Dist., Nova Scotia, Geol. Surv. Canada, Mem. 60, 1914, p. 118.

C. W. Drysdale: Geology of the Franklin Mining Camp, Brit. Col., Mem. 56, Geol. Surv. Canada, 1915, pp. 96 and 128.

A. M. Bateman: Geology and Ore Deposits of the Bridge River District, British Columbia, Memoir, Geol. Surv. Canada, in press.

Bruce Rose: Geology of the Savona District, British Columbia, Memoir, Geol. Surv. Canada, in press.

being more and more studied by modern petrographic methods, and as previously noted, there are all gradational varieties of transition from them into tuffs.

Classification of Material.

Fragmental volcanic material may be roughly divided for convenience into pieces the size of an apple and upward as *volcanic bombs;* those the size of nuts, *lapilli;* ones like small peas or shot, *volcanic ashes*; while the finest is *volcanic dust.* The divisional points may be supposed to lie midway between these sizes. The coarser material, the bombs, lapilli, and much of the ash, may fall around and near the vent and produce beds of *breccia;* the lighter ashes and dust, supported and carried by air currents, tend to fall after these and at greater and greater distances from the vent; their compacted material is known as *tuff.* Naturally all gradations both in vertical and horizontal directions will occur between tuffs and breccias. The term *volcanic conglomerate,* sometimes used in the place of breccia, should be restricted to water-laid conglomerates consisting of volcanic materials which exhibit erosional wear. In the use of *volcanic agglomerate* it would be best to follow Geikie* and confine the use of the term to the tumultuous assemblage of blocks, often of large size, which may be found filling the upper portion of old volcanic conduits.

It is obvious from the sizes mentioned that the determination of volcanic breccia is a matter of megascopic study, best, perhaps, performed in the field. If the microscope is to throw any light on rocks which are supposed to have this origin it will be chiefly by a study of the tuffaceous filling between the larger pieces, aided perhaps by the nature of their contours. It is, therefore, the tuffs which must be the subject of microscopical study, and what knowledge they afford can be easily carried over to include the breccias.

Composition of Tuffs.—Tuffs are composed of three things: *a,* glass; *b,* crystals of individual minerals; and *c,* fragments of rocks which may be holocrystalline or partly glassy. While all degrees of purity and admixture of these three occur, accordingly as one or the other predominates or gives decisive character to the material, we may distinguish *vitric tuffs, crystal tuffs,* and *lithic tuffs;* the use of "vitric" and "lithic" is suggested instead of the more common "glassy" and "stony" in order to avoid the misapprehension that the outward appearance of the material is referred to. Tuffs also may be fresh, altered, or metamorphosed, and each of these three stages

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* Text-book of Geology, 4th Ed., 1903, p. 173.

demands consideration. They may differ also in their petrogenic nature, the chemico-mineralogical differences depending on the kind of magma; whether rhyolitic, trachytic, andesitic, or basaltic, etc., and these also require attention. We will commence with the simplest type, the fresh vitric tuffs.

Vitric Tuffs.

Formation of Tuffs.—Since tuffs are produced by the sudden violent expansion or explosion of gases in a more or less viscous magma it may be well to consider this phenomenon for a moment. It is obvious, in view of the quantities of ash and dust that are almost instantaneously produced, sometimes reaching vast proportions, that it cannot be the result of bubbles merely passing out from, or forming at, the surface of the liquid melt. They must indeed be produced simultaneously through a body of the magma which is in the conduit. There is some analogy here to the sudden liberation of steam, on the relief of pressure by overflowage from the pipe of a geyser, occasioning its discharge. But it differs from that of a geyser in that in the latter there is only one medium, the water; while in the magma there are the volatile gases and the non-volatile more or less viscous silicate melt. If the sudden production of the gas bubbles does not take place with expansive force sufficient to rupture the magma, the latter would expand, sometimes enormously, in volume, and a pumice or rock froth would result. Where ash and dust are formed the rending of the magma must occur, and the more complete this is the finer the resultant product will be. The expansion of gas and rupturing begin in a liquid medium; the resulting product falls as a rigid glass. We do not know of course the exact march of events between these points; but it is clear that the magma ruptures into separated masses of different sizes, as the volume of mingled gases and molten glass rush out of the conduit. The separate masses are themselves swelling and flying apart into smaller ones as they ascend, and this continues until the stiffening of the glass and the lessening of the expansion of the gas through cooling bring the process to an end. This carries us to the point where we may consider the forms of the resulting particles.

Forms of Particles.—A bubble of gas expanding on the surface, either of the original magma or of one of the projected masses, forms a vesicle or bulb, whose wall is thickest at the top and whose sides become thinner and thinner as it expands away from the surface, until they are finally ruptured and the bowl-shaped body is driven from the parent mass. Such a form is shown in *a* of fig. 1. It is evident that unless excessively minute such vesicles will be broken into smaller fragments by violent collisions in the outrushing cloud of gas and ash, or by weight of superincumbent material after deposition. It is also to be noted that the form of such fragments, with the surface large in proportion to the weight, is an excellent one for floating and long waftage by air currents. In thin sections of vitric tuffs, sections of such vesicles, or their fragments, appear mostly as lune- or sickle-shaped pieces of glass, as illustrated in *b*, fig. 1. It commonly happens also that in the projected particles of magma a number of contiguous or even coalescing bubbles are forming and bursting at the same time. The fragments of the cell walls which are left will show various cusp-like shapes of the character illustrated in *c*, fig. 1. A further extension of this leads to cases where, owing to increasing viscosity, or to greater depth from the surface in the magma particle, not all of the bubbles are able to burst their cell walls and some remain imprisoned in the glass. The effect is then like *d* in fig. 1. Some of the spheroidal openings may of course be sections of bubble pits seated on the surface of the particle after *a* has been blown off. In the rending of the magma it may happen also that particles of it are driven apart while they still have points of attachment; if the magma is not too excessively viscous they will draw out threads of glass after them. Tiny broken pieces of such threads are seen as rod-like bodies, sometimes carrying inclusions or drawn-out vesicles; *e*, fig. 1. This is the same as the well known Pélé's hair.

Fig. 1.

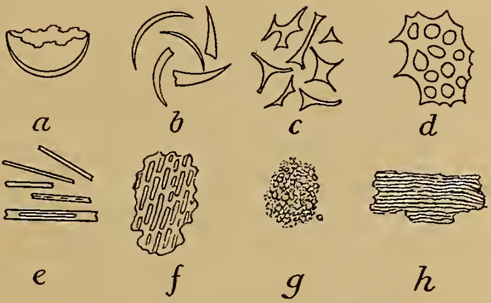

Fig. 1. Forms of glass strands and particles in tuff.

Pieces of the character of *d*, fig. 1 are larger than *b*, *c* and *e* and represent transitions from dust into ash; as their dimensions grow they pass into lapilli. Not infrequently one dis-covers they have been pulled out; that is, they are the same as *e* on a larger scale. This is shown in *f*, fig. 1, where the vesicles are elongated. A transverse section of this does not exhibit the elongation, but appears as in *d*. If the elongation is very pronounced the particle may resemble a bundle of fibers, as in *h*, fig. 1. A transverse section of this shows the ends of the fibers in a berry-like grouping; *g*, fig. 1.

Section of a Vitric Tuff.—A typical example of a vitric tuff from a rhyolitic magma, which exhibits well the various forms of glass particles mentioned above, is shown by the drawing in fig. 2. This tuff is relatively little altered in that

FIG. 2.

FIG. 2. Rhyolitic vitric tuff from Checkerboard Creek, Castle Mountain Mining District, Montana, showing typical vitroclastic structure. Actual diameter of field 2 mm.

the glass shards are unchanged in substance and do not act on polarized light. The interstitial material between them is in some cases more minute fragments of glass, while much of it appears by transmitted light excessively fine granular and largely of a brown color; the nature of the latter in part is indeterminable and it may consist of altered glass dust, and in large part it is chalcedony, deposited hydrous silica, in numerous areas and patches, as shown by its refractive index, double refraction and fibrous radiating nature; which causes it to yield between crossed nicols, on revolving the plate, a stationary black cross like that of as pherulite. This chalcedony has a rich brown color by transmitted light. While the tuff in the hand specimen, like so many others, is colored brownish by limonitic pigment, the color of the chalcedony, as well as that of other patches of finely aggregated particles, is so much deeper by transmitted than by reflected light that it is clear this brown color is in large part due to the unequal refraction and internal reflection of light in passing through aggregated fibers and particles, whereby the blue rays are absorbed and the red-orange ones transmitted, as explained by the writer in the case of spherulites.* This effect is seen in many tuffs. The tuff illustrated is not an absolutely pure vitric type in that occasional fragments of quartz, feldspar, augite, hornblende and iron ore occur in it; it has been analyzed and previously described.† It has about the strength and coherency of a firm chalk.

Loose Volcanic Dust.—With a series of excessively fine volcanic dust deposits of a loose uncompacted nature which, in some cases at least, have evidently been transported long distances from their original sources if we may judge by the places in which they occur, Oklahoma for example, a study has been made by directly imbedding the particles, without sectioning, in balsam. In these it has been found that while the various shapes mentioned above occur to a greater or lesser degree, the most prevalent one is that of a thin film of glass of a triangular shape whose sides are curved, forming a spherical triangle. By raising and lowering the objective one may often observe that the film is not flat, but more or less slightly dished, like a wash-glass, thus indicating that it is part of the glass skin or bulb covering a large bubble. These occur with great variety in the detail of the forms, examples of which are shown in *a*, fig. 3. Some of these are thicker on one side than on the other, giving at times a sphenoidal or axe-like

FIG. 3.

FIG. 3. Shapes of glass particles in volcanic dust.

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* Artificial Lava Flow and Its Spherulitic Crystallization. This Jour., vol. xxx, 101, 1910.

† Castle Mountain Mining District, Bull. U. S. G. S., No. 139, p. 127.

effect. In other cases the films are ribbed, as illustrated in *b*, fig. 3, indicating the cell walls of other bubbles. Sections through such fragments shown in fig. 3 would obviously yield shapes like some of those seen in the tuff, fig. 2.

In some of these dusts there are great numbers of glass fragments of entirely irregular, haphazard forms and there may be some question regarding the influence of the viscosity of the magma, at the moment of explosion, on the shapes of the particles produced. For with increasing stiffness the less opportunity there would be for normal bubble expansion and the formation of vesicular structures, and the more sudden and complete would be rending and shattering of the glassy melt, with the production of irregular fragments. This would also be more likely to happen in highly siliceous magmas, since they are the more viscous ones. In addition it may be noted that the greater the distance a volcanic dust is carried by air currents from its source, the more purely glassy it will be, since the higher specific gravity of any crystalline material will tend more and more to sift the latter out.

Vitroclastic Structure.—The particular type of microstructure which distinguishes vitric tuffs and is illustrated in fig. 2 deserves a special name. It is as characteristic for these rocks, both when fresh and when altered, as certain textures are for some igneous ones, or particular structures are for certain organisms occurring as fossils in the sedimentary rocks. It has been designated "ash structure" by Mügge,* a term also used by Rosenbusch : but there are objections to this name in that volcanic "ash," as the term is commonly used, indicates coarser material than that which composes the dust that characteristically exhibits this structure. Most "ash" is really composed of fine lapilli, is largely crystalline, and under the microscope is a very fine breccia. If the structure is seen in rocks composed of ash it is in the finer portion composed of dust that fills in between these micro-lapilli. Hence it is proposed to name it the *vitroclastic* structure, a term whose meaning is sufficiently obvious and whose faulty construction, like that of vitrophyre, from the standpoint of etymology, in that it is composed of roots from two languages, it is hoped may be forgiven since both components are so well known to all petrographers. There is a suggestion of the sedimentary rocks also in the term, which is not bad, since the tuffs often form gradations between that great group and the igneous ones, as previously mentioned.

Magmatic Relations of Vitric Tuffs.—While many exceptions to this general rule may be found, it is true that the most frequent examples and largest masses of vitric tuffs are found

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* Op. cit.

in those derived from rhyolitic and dacitic magmas; less frequently from those of trachytic or andesitic composition: and still less so from basaltic ones. This of course depends in great measure on the inversely varying viscosity and crystallizability of the different magmas; the more viscous felsic ones forming glass under conditions where the more fluid mafic ones readily crystallize. The exact magmatic relations of a vitric tuff can only be determined by chemical analysis, but it may be noted that the glass of fresh felsic varieties is usually clear and colorless; that of basaltic ones colored brown. This applies to them of course only as they appear in thin section by transmitted light and to the glass particles themselves, not to interstitial matter which may be colored, as previously discussed.

It should be mentioned here that basaltic tuffs, composed of angular or concave edged particles of brown glass, are called *palagonite.* They are often vesicular and may enclose microlites of plagioclase or crystals of augite or olivine; often the fragments are outlined by bands of a lighter or different color, which are sometimes isotropic like the glass cores, sometimes weakly birefringent. Such banding indicates a certain degree of alteration.

Crystal Tuffs.

While it has happened, and perhaps not infrequently, considering the number of instances which have been observed, that volcanoes have projected material consisting of practically nothing but crystals of a particular mineral, such as augite, olivine, feldspar, leucite, etc.; and even masses of loose titanite crystals are mentioned by Doelter* as occurring on one of the Cape Verde volcanic islands; tuffs, composed entirely of crystals, must be very rare, and their origin as such might be difficult to determine. On the other hand, crystals of minerals, the kinds depending largely on the nature of the magma, either perfect in form or more or less fragmental, are found in nearly all tuffs; and when they become a dominating or striking feature of them the rocks may be referred to this division. It may be said, however, at the outset that while crystal tuffs of acidic felsic magmas are common, those of basaltic ones are at least comparatively rare.

Origin of the Crystals.—This may be two fold; they may have originated in the magma itself, which, caught in the act of crystallizing by the explosion, consisted of a mass of crystals mingled with liquid; or they may have come from disrupted and shattered portions of the rocky walls through which the vent has been drilled. Not infrequently a mingling of both

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* Petrogenesis, p. 147, 1906.

may be found in the same tuff. To determine which origin the crystals of a particular mineral in a tuff may have had, two features should be considered. The first is whether, regarding the general petrologic nature of the tuff, as determined by its association with other igneous rocks in the field, its chemical composition provided an analysis is made, or in lack of it by the character of the general assemblage of crystalline material it contains, such a mineral could be considered one of its normal components. Thus in a tuff which examination had shown to be of trachytic or phonolitic nature, crystals of quartz would have to be regarded as of an origin foreign to the magma and therefore in the second class. The second feature relates to peculiarities which the crystals themselves may show. The ones of the first class, produced in the liquid magma, may be regarded as prematurely born phenocrysts and, like the phenocrysts of the lavas, they may be spongy, filled with inclusions consisting of other minerals, indeterminate microlites or blebs of glass, or contain cavities filled with liquids or gas. They may also be corroded, with deep embayments, the latter filled perhaps with glass, as so often seen in quartzes and olivines; and in addition they may have, especially with feldspars, the clear glassy appearance associated with sanidine, in contrast with the ordinary habit of the feldspars of the granular rocks. On the other hand, fragmental crystal material torn from older, deeper-seated rocks of the basement, or projected by explosion, may be quite lacking in such distinctive properties. The student, however, should guard against thinking that these features can be always used as an invariable receipt for making such a distinction. They may be quite wanting, or the crystals may have been derived from older lavas forming part of the cone, which may have been projected by explosion. But if used with discretion, in combination with other circumstances to be described later under lithic tuffs, they may be of great service. In case the crystals show corrosive embayments filled with a crystallized groundmass, like the quartzes of rhyolites or the olivines of basalts, it may be safely inferred that they have been derived from older lavas.

Forms of the Crystals.—The forms exhibited by crystals in tuffs may be in places, as is well known, strikingly perfect, furnishing when they are of sufficient size some of the best of cabinet specimens, like the augites from the tuffs near Aussig in Bohemia. With the lens, quite minute ones of perfect development may be observed, and if the tuff is not too indurated, picked out with a knife or needle point and examined under a low power on the microscope stage. Such crystals, complete in their outward crystal form, must be of the first class mentioned above, for if embedded in solid rock they would of necessity have been shattered by the forces which fragmented it. More commonly the crystals seen in these tuffs consist of broken pieces which in thin section exhibit here and there a crystal outline, but in general show no definite shape. The student must guard against imagining that he can see in them the cuspate and lune-like forms which are characteristic of the vitroclastic texture shown by glass shards; obviously such structures could not be produced by the shattering of solid substances. The resemblances to it are most frequently seen in pieces of quartz and are due to the conchoidal fracture of the latter.

It is stated by Harker* that in crystal tuffs there is frequently a characteristic arrangement, by which the crystals stand in the finer matrix with their longer axes at right angles to its lamination, as if they had fallen into it from above.

Interstitial Filling.—In a fresh crystal tuff, whose substance is of direct magmatic origin, the material between the crystals is composed of glass shards and the finest dust, often almost sub-microscopic particles of both, produced partly by the explosion and partly by attrition of the larger fragments upon one another. It may, therefore, exhibit the vitroclastic structure and be itself the best proof of the tuffaceous nature of the deposit. But since the crystals may not always be of direct magmatic origin, that is, of the first class previously mentioned, so also much of the filling between them may be derived from previously formed rocks. In this case the tuffs form gradations into the lithic types described later. Generally speaking, however, the filling in these tuffs is more or less altered, as will be described later. An example of a typical crystal tuff of rhyolitic origin is shown in fig. 4. The crystals are mostly quartz and feldspar with a few of biotite and hornblende.

Lithic Tuffs.

The essential feature of tuffs of this class, as previously explained, is the presence in them to a striking or dominating degree, of fragments of previously formed rocks. Several different modes of origin of these may be conceived. Thus instances are known where volcanic vents have been blown through a sedimentary series, shattering and powdering the beds and projecting the comminuted material, without, however, being followed by any rise to the surface or escape of magma, or but very little, as in some of the maaren of the volcanic Eifel. Crater pits formed by such "blow outs," to use

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* Harker and Marr: Shap Granite and Associated Rocks, Quart. Jour. Geol. Soc., xlvii, p. 299, 1891.

a miner's term, would be surrounded by a deposit in fragmental condition of the bedded rocks affected, with little or no volcanic material; whether they should be called "tuffs," or not, must be largely a matter of individual opinion. Also, at any time during eruptions, material may be torn from the walls of the conduit where it passes through the sedimentaries or crystallines forming the basement of the volcano, and appear in the tuffs. But the most prominent kinds of fragmented rocks present in lithic tuffs are, in general, lavas of a class similar to that of the exploding magma, or genetically related to it. While they may be portions of the cone already formed it may be suspected that more often they are parts of a solidified and more or less completely crystallized crust, which has formed by the freezing of the upper layers of the magma column during a period of quiescence in its volcanic activity, and which, by the rising pressure of the accumulating vapors below it, is finally comminuted when explosion occurs. An average lithic tuff consists then largely of tiny fragments of rhyolite, trachyte, phonolite, or andesite, etc., as the case may be, with their characteristic minerals and textures in those stages of development which the particular rock had attained on solidification, and with an interfilling of glass shards, bits of pumice, mineral dust, etc., mingled usually with more or less distinct crystal fragments. The interfilling may

Fig. 4.

Fig. 4. Rhyolitic crystal tuff from the Antelope Range, Utah. Crystals shown polarizing between crossed nicols; filling of glass dust, etc., in plain light. Actual area, 5^{mm} in diameter.

exhibit clearly the vitroclastic texture, but as in all tuffs, this depends in great measure on the recency and state of preservation of the rock, as described later. The size of the stony particles, which must be large enough in general for the particular kind of lava to be recognized, takes them out of the class of volcanic dust, into that of volcanic ash, mentioned at the beginning of this article, and we see, therefore, that there is, in a general way, a progression in tuffs from vitric types—the finest—through crystal tuffs, into lithic ones and then into breccias. An example of a lithic tuff is seen in fig. 5.

Fig. 5.

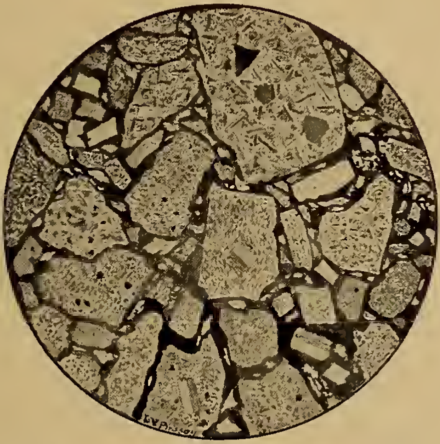

Fig. 5. Lithic tuff of trachyandesitic nature, from the Euganean Hills, Italy; actual size, 5^{mm} in diameter; nicols crossed.

In determining the position of a tuff in petrographic classification, that is, whether it is rhyolitic, trachytic, andesitic, etc., the student should bear in mind, and this applies more especially to the crystal and lithic varieties, that he is liable to encounter among the ash particles, as may be inferred from what has been previously stated, bits of rocks and minerals quite foreign to a lava of the particular kind with which he may collate it. His determination, therefore, should be based on the average character of the dominant ash particles.

Average Tuffs.

In the foregoing discussion three special types of tuff have been selected and described for divisional purposes in classification. It should not, however, be supposed that all tuffs will clearly fall into one or the other of these three classes. While many will, the majority of these rocks will be found to be intermediate in character; for all gradations between the three will be found in nature, with the exception that tuffs composed of glass dust with stony ash particles, but devoid of individual mineral crystals, must be extremely rare if indeed they can occur. The most common kinds are those containing in variable proportions all three ingredients; such transitional character should be taken into consideration in determining and naming them.

Tuffaceous Sedimentaries.

Where tuffs have fallen into water, or have been quickly washed down into it after their deposition, they may not have been essentially altered in composition or characteristic micro-textures, and although, perhaps, beautifully stratified their recognition by microscopic study may be relatively easy. In such cases also they may grade into, or be alternated with, distinct volcanic conglomerates or breccias, and the microscopic studies of the latter in the field may greatly aid in their determination, especially when the tuffs are altered. But when tuffs have been exposed to weathering for some time, so that a considerable amount of the alterations, which they so readily undergo and which will be described later, has occurred in them and they are then washed down, mingled with greater or lesser quantities of ordinary land waste, and deposited anew, it is often very difficult to decide in such beds whether tuffaceous material is present or not. Under such circumstances the glass shards are usually destroyed and with them the characteristic vitroclastic structure. If, fortunately, they are found, then decisively tuffaceous material is present. If not, search should be made for ash-sized particles of pumice, which may exhibit the vesicular structure and may possibly still prove to be of glass; for crystals with the peculiarities mentioned under crystal tuffs; and for tiny fragments like those of lithic tuffs. If no glass can be found, or proved to have been present, the determination cannot be certain if it rests on only one observed characteristic; it can only become so when a sufficient assemblage of them is shown to be present. As petrographic studies are progressively made of the later bedded rocks of the region of the American Cordillera, it is certain that vast amounts of tuffaceous sediments will be found in them; in studying them criteria of the nature advanced in this paper will be found most useful.

Alteration of Tuffs.

It is the exception, rather than the rule, to find tuffs in the condition in which they are when freshly deposited. For one thing their loose porous texture permits the ready passage through them of meteoric waters carrying substances in solution, which may attack them and at the same time by deposition introduce foreign substances into them, which in many cases serves to cement them into more or less firm rocks. For another thing, the glass, which may be a prominent or even dominating ingredient, is a substance chemically in unstable equilibrium and therefore ready on the slightest pretext to alter into other and more stable forms of matter. The same is true, only in lesser degree, of many of the crystalline minerals they contain, in that these compounds have formed originally, and are in equilibria, under a very different set of physical conditions from those in which they are subsequently placed. In this latter respect tuffs, however, are not of course different from any of the crystalline igneous rocks. In addition to these causes of alteration tuffs, like all other rocks of whatever origin, may be subjected to metamorphism, both contact and general, and may be more or less modified and even so profoundly that no trace of their original character may remain. To undertake to discuss fully all such possibilities would be almost equivalent to a treatise on the general subject of metamorphism and far beyond the limits of this article. It is proposed here, therefore, only to sketch some of the more important features of these changes and the results that follow from them, with special reference to the tuff nature of the material operated upon. These broad outlines must be regarded by the student as indications of the paths to be followed in the investigation of particular cases. They may be discussed under the following general headings: *Weathering and Consolidation; Devitrification; Contact Metamorphism;* and *General Metamorphism.*

Weathering and Consolidation.

Weathering and consolidation are not of course one and the same process and yet where the first is taking place the second in a measure, in depths below, must be also occurring. The weathering of tuffs is comparatively easy where they are loose and uncompacted, owing to the ready access of air and moisture and also to the relatively large surface areas exposed by such fine grains. Hence the feldspathic tuffs are readily kaolinized and converted into soft earthy masses. One of the earliest indications of a change in tuffs, when examined in section, is the deposition in them of some form of hydrated silica, opal, chalcedony, etc. This has been already mentioned in the description of the vitroclastic tuff from Castle Mountain. Every stage of this saturation of the felsic tuffs by hydrated silica may be found until eventually they may pass into extremely dense flinty rocks, resembling so closely dense rhyolites, novaculites, jaspers, etc., that it becomes impossible to distinguish their real nature in the field, more especially as they may assume lively colors of green, red, yellow and brown. Some striking instances of these rocks have been found in North Carolina and Georgia among the ancient volcanics of the Piedmont plateau. In thin section evident remains of the vitroclastic texture may sometimes be observed, establishing in connection with the shattered condition and nature of the accompanying crystals, their tuff-like character; but often these are not present in any decisive fashion and in this case, while chemical analysis may prove their igneous origin, in contrast with jaspilites and novaculites, it cannot be determined whether one is dealing with tuffs or the lavas corresponding to them. There is apt to be in these cases thorough devitrification, as described later, which is another obscuring element. Where the tuffs have been merely altered by weathering the particles become turbid from the separation of kaolin, hydrated iron ore, and carbonates, and lie in an impure cement of minute granules of these substances which tend to obscure the characteristic structure. An excellent example of an altered tuff has been figured by Professor Bascom* from South Mountain, in which the structure is well preserved. Some altered tuffs, more especially those of the less siliceous and more andesitic types, appear almost wholly like aggregated masses of carbonates in the section; one feels inclined to believe at times that they must have been overlain by limestones whose substance has been leached down and deposited in them. Mingled with these carbonates are earthy masses of iron ore.

Probably from a somewhat different type of alteration the fine tuffs may be changed into minute scales of sericitic mica mingled with granules of quartz. Along with them is apt to occur leaves and shreds of chlorite. It is often extremely difficult, or even impossible, to distinguish in the finer granules whether one is dealing with sericite or kaolinite; a difficulty alluded to by Rosenbusch.† In basaltic tuffs, as in the so-called palagonites, the alteration leads to the formation of secondary silica, zeolites, chloritic minerals, carbonates, and limonite. The cement between the ash particles is first attacked and as the alteration proceeds with the particles themselves, the original structure may be more and more obscured until it is finally lost. Yet even when the vitroclastic texture has disappeared, the fragmental appearance

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*Ancient Volcanic Rocks of South Mountain, Penna., Bull. 136, U. S. G. S., Pl. XXV, 1896.

† Mikrophysiog. Ergussgesteine, 4th Aufl., p. 870, 1908.

of the rock in the section with the remains of the vesicular character of many of the particles, often made clear by the filling of the vesicles with secondary substances, may greatly aid in determining its original tuff-like nature.

Devitrification.—In course of time, and aided perhaps by heat and pressure, vitric tuffs like other glassy rocks may become devitrified and pass into a crystalline condition. Considering first the tuffs formed from felsic magmas, the more common kinds, this process consists essentially in a change of the glass into feldspars and quartz; it is quite similar to the devitrification of glassy rhyolites which has been mentioned by many writers and fully described by Professor Bascom.* The result between crossed nicols is that the whole rock appears composed of a mosaic of feebly polarizing particles, producing a so-called "pepper and salt" appearance, which becomes so minute in texture in places as to be almost micro-cryptocrystalline. Along with this change there is liable to be some chemical alteration and the introduction of new material; thus secondary silica in the form of chalcedony; shreds of sericite, patches of carbonates, and limonitic material in greater or lesser amounts may be found here and there. Between crossed nicols little or nothing as to the origin of such rocks may be gathered from the section; they resemble glassy lavas which

FIG. 6.

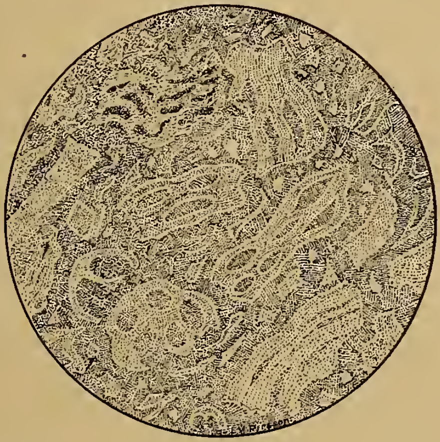

FIG. 6. Devitrified and partly silicified rhyolite tuff from the Oelberg, Schriesheim, Baden. Actual diameter 2^{mm}.

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*Ancient Volcanic Rocks of South Mountain, Penna., U. S. G. S., Bull., 136, 1896.

have experienced similar changes. But without the upper nicol, the condenser lowered, and by using a fairly high powered objective, careful study of the section will often bring out the original vitroclastic texture. By raising and lowering the objective the shapes of the original dust and ash particles become visible by the lightening of their edges from a Becke light band, due to differences in refractive indices. One can then trace out the forms of the shards, threads, cusps, vesicles, etc., that have been previously described. An example of this kind is seen in fig. 6; it should not be thought that the texture shows as clearly in the section as in the illustration; if the writer had depicted it as faintly as much of it actually appears, the drawing could not have been reproduced. The vitroclastic nature of the rock from the Oelberg was first determined by Andreae and Osann* and a somewhat similar instance has been described and figured by G. H. Williams.† In other cases the recognition of the texture in plain light may be aided by slight differences in coloration or outlining of the parts by ferritic material. In tuffs from mafic magmas devitrification is a process of alteration into secondary minerals as described above under alteration.

Metamorphism of Tuffs.

Contact Metamorphism.—The effect of invading magmas upon already solidified igneous rocks is a problem which has not yet received the attention from petrographers which its importance demands, and this is probably most marked in the case of volcanic tuffs. Except in one instance mentioned later it has not been studied by the writer or his students, and reference must be had therefore to the literature of contact metamorphism. The most detailed study appears to be that made by Harker and Marr‡ on ancient rhyolitic and andesitic tuffs in the contact zone of the Shap granite in Westmorland, England. The former are recognized in the field as of explosive nature by the angular fragments of rhyolite and some andesite which they contain, and are thus classed as breccias; in addition crystals of feldspar, quartz, etc., occur. The proportion of fine matrix to fragments varies in different beds. The fine ash and dust away from the contact zone is seen to be considerably altered, having been extensively silicified, and with the feldspar phenocrysts replaced by masses of epidote; this alteration is believed to have occurred before intrusion of the granite. As one passes into the contact zone the first stage is the forma-

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* Erläut. zu Blatt. Heidelberg d. geol. Spezial Karte Baden, 1896.

† Silicified Glass Breccia of Vermilion River, Sudbury Dis't., Bull. Geol. Soc. Amer., vol. ii, p. 138, 1891.

‡ The Shap Granite and Associated Rocks, Quart. Jour. Geol. Soc., vol. xlvii, p. 266, 1891.

tion of a brown mica so minutely divided as to act like a pigment and to be individually indeterminable; but as one approaches nearer the granite the particles increase in size until they can be definitely recognized and, eventually, they pass into fewer, relatively large biotite flakes. In addition the rock is spotted minutely, and these spots also increase in size; in the section they are perceived to be areas free from biotite. In the next stage near the granite, although megascopically the rock has retained its structure, by which it may be recognized in the field, the thin section shows it has been completely recrystallized. Brown mica, derived from a green chloritoid mineral, and iron ore, occur in streaks showing the original lamination. The rock is mostly composed of a fine aggregate of clear feldspar with probably some quartz, formed during the metamorphism, with which are associated white mica and granules of cyanite. In some cases the last two minerals are wanting, but always the mosaic of new feldspar, quartz, and brown mica is present. Where the original rocks were greatly silicified the effect is much less marked and brown mica is the only new mineral.

With respect to andesitic tuffs the changes are of a similar nature, and quite like those observed in flows of andesite, with which the tuffs are associated. The tuffs were of the crystal-lithic type with fragments of andesite, some of rhyolite, and crystals of the same character as the andesitic phenocrysts. They had been much altered previous to the metamorphism; the feldspars were turbid and the augite changed to a chloritic mineral, while calcite and secondary quartz were present. As in the rhyolites the first sign of metamorphism is the appearance of brown mica, while green hornblende and actinolite are also found with it. Octahedrons of magnetite occur, and these minerals are seen in a fine granular groundmass of recrystallized feldspar and quartz, the former showing the albite twinning. The original phenocrystic feldspars are replaced by aggregates of new feldspar and quartz with some biotite.

Quite similar effects were found by Barrell* to have been induced in andesites and andesitic tuffs by the intrusion of the Boulder bathylith at Elkhorn, Montana. He says that "sprinkled like a veil over all the rock, both phenocrysts and groundmass, are flakes of biotite and hornblende. These tend to be confined to strings and patches over the plagioclase phenocrysts, and are taken to show a recrystallization during a period of intense metamorphism, accompanied by a dissemination of the elements of the hornblende and biotite into the cracks of the feldspars."

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* Geology of the Elkhorn Mining Dis't., 22d Ann. Rep. U. S. Geol. Surv., Pt. II, p. 526, 1902.

Contact metamorphism of trachytic ("orthophyre") tuffs near Harzburg by the Brocken granite has been studied by Erdmannsdörfer,* who states that the altered rock has the hornfels texture and consists mainly of brown biotite, considerable enstatite and anthophyllite, the latter often in fine needles which may aggregate into spherulites, some augite, much orthoclase with a little plagioclase and quartz. The former large embedded crystals of orthoclase have been changed into aggregates of various minerals.

The effect of contact metamorphism upon basaltic tuffs has been studied by few observers.† Probably where the alteration of diabases has been described in the literature, as by the English and Saxon‡ geologists, the metamorphism of tuffs has been included; Rosenbusch suggests this in one case.§ It might be much more difficult to decide in the changed rock whether it had been a basalt (or diabase) or its tuff than with more felsic, siliceous types. In some cases the action leads to the formation of schistose rocks composed of actinolite or anthophyllite in needles, or common green hornblende in granules with a background of plagioclase, augite, biotite, garnet, and other minerals in varying amounts. Harker mentions biotite as the most prominent mineral and states that large feldspars are recrystallized into mosaics or replaced by pseudomorphs of epidote; this is much like the effects mentioned above as occurring in the andesitic tuffs.

General or dynamic metamorphism. — The distinction between the effects produced by the various processes which tend to alter tuffs, such as contact metamorphism, devitrification and silicification, previously described, and general metamorphism, is for the most part a theoretical rather than a practical one. In metamorphic complexes there occur rocks which investigation will show to be of tuffaceous origin and whose characters will be similar in the main to those which have been described above. The especial feature which is to be added in dynamic metamorphism is mashing and shearing which destroy and obliterate the diagnostic characters of tuffs in proportion to the extent to which they have operated. In felsic tuffs the new mineral which is generated by their effect upon the feldspar is sericite and the final result is to reduce such tuffs to fissile sericite schists or phyllites. Since the same

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* Devonischen Eruptivgest. und Tuffe bei Harzburg, Jahrb. d. k. preuss. Geol. Landanst., xxv, p. 45, 1904.

† R. Beck, Amphibolitizirung von Diabasgesteinen, etc., Zeitschr. d. D. G. Ges., xliii, p. 259, 1891; Harker and Marr, Metamorphic Rocks around Shap Granite, Quart. Jour. Geol. Soc., xlix, p. 360, 1893.

‡ Conf. Rosenbusch, Mass. Gest., 4th Aufl., p. 120, 1907.

§ Barrois, Excursion aux environs de Morlaix, Bull. Soc. Geol. Fr. (3), xiv, 888, 1886.

thing may happen to the corresponding lavas a decision in the case of end products, as to whether the rock was originally tuff or lava, is generally impossible. Quite an analogous result is reached with mafic, or basic, tuffs which in their turn become converted into greenstone or hornblende schists, just as happens with their corresponding diabases or basalts. Doubts may even arise in some cases as to whether such schistose rocks are really of igneous origin, and a chemical analysis may then be of the greatest service in supplementing the field and microscopic observations.

In general it may be said that while sericite is the most characteristic mineral of completely metamorphosed felsic tuffs, it is usually more or less accompanied by quartz, biotite, chlorite, epidote and clinozoisite ; while in the mafic ones actinolite and chlorite, also accompanied by more or less biotite, clinozoisite and epidote are common.

Where the destruction has not been so complete, however, then the characteristics of tuffs should be carefully sought in the sections. It may be remarked in this connection that the chances of their survival are much better in felsic than in mafic ones. Remains of the vitroclastic texture, as indicated in fig. 2, if found, may be conclusive ; if not, a secondary line of evidence may be sought in the nature of the included crystals or their fragments if such are present, as discussed previously under crystal tuffs. Evidence of this kind by itself will probably not be decisive as between lavas and the corresponding tuffs, but supplemented by facts to be seen in the field it may become so ; for it must not be forgotten that tuffs, like sediments, are often well bedded and a combination of bedding and angular phenocrystic fragments speaks strongly in favor of tuffaceous origin. An excellent example of the determination of this source for the material of a gneiss (hälleflintgneis) has been given by Bäckström.* It is to be understood that only fine tuffs are here referred to ; in the case of breccias the evidence afforded by the megascopic structure of the rocks is of the highest value and may be quite decisive by itself, without reference to microscopic or chemical determinations, as shown for example in various parts of the Piedmont plateau by the work of Professors Bascom, Pogue, and Dr. Laney whose papers have been previously referred to in this article.

Sheffield Scientific School of Yale University,
New Haven, Conn., March, 1915.

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* Vestanåfältet, K. Svensk. Vetenskaps. Akad. Hand., xxix, No. 4, pp. 52, 122, 1897 ; Conf. also, O. Nordenskjöld, Archaeische Ergussgesteine aus Småland. Bull. Geol. Inst. of Upsala, No. 2, vol. i, p. 81, 1893.

Art. XIX.—*Northfieldite, Pegmatite, and Pegmatite Schist;* by B. K. Emerson.

The band of granite gneiss, which runs up through Wilbraham, Mass., and, interruped by the tonalite in Belchertown, continues north through Pelham to Northfield, is at its south end a quite basic rock like the Monson band next east, but as it crosses Pelham it is found by chemical and microscopic analyses to become gradually a very acid one. The Monson rock in the southern part contains 65·02 of silica, the Pelham gneiss in Pelham 72·45 per cent of silica and in the northern area in Erving 74·15 per cent. The Monson extends in a broad many lobed mass across the state and has everywhere a wide diorite border bed against the adjacent schists and very generally an equally wide band occurs inside this border, separating it from the normal granite, which is whiter and often finer grained than the granite, often indeed developed as an aplite. I have followed the diorite band 136 miles around the Monson batholite in Massachusetts. The above mentioned gneiss in Wilbraham to the west of the Monson has the same diorite and aplite band but as it reappears in Belchertown these bands become thinner and in Pelham the diorite band thins out and disappears and the aplite is replaced by a band of contact quartz rock which thickens and grows coarser as it goes north and becomes in Crag Mountain over 300 feet thick. Its coarser varieties resemble a vein quartz, or greisen, or pegmatite minus feldspar, its finer, a quartzite like the Cambrian in the Berkshires. As a pegmatite or aplite dike may pass into a quartz vein, the central mass of the batholite seems here to pass on a large scale up into this quartzose border variant.

While the exterior resemblance is close, it is not wholly satisfactory to apply the name greisen to this rock, since it does not seem to be the result of later pneumatolitic changes whereby the feldspar of the granite has been removed, but to be rather an original ultra-acid contact differentiate and deposit of the magma. Since it is a member of the unaltered plutonic series and can not be called a vein quartz, a quartzite, or a greisen, it is named here *northfieldite*, from the mass in Northfield forming Crag Mountain.

The bedding of the Pelham gneiss forms a broad, flat arch, horizontal over a wide central portion and with low dip to the east and west along the east and west border, respectively. The bedding of the northfieldite is conformable with that of the granite-gneiss, and in many places the gneiss can be seen to pass up into the northfieldite by easy transition.

This is especially well exposed in the type localities of the two variants of the rock, which are described below, that of Crag Mountain in Northfield and Mt. Orient in Pelham. The great ridge of Brush and Crag Mountains in Northfield is elevated above the surrounding country because it is made up of this coarse resistant quartz rock. Its southern apex, Crag Mountain, with its steep southern scarp is a prominent landmark from the valley in Montague or Northfield.

The rock has the aspect of a greisen, a coarse pegmatite without feldspar. It is a coarse vein-quartz in flat bands about an inch thick with distant films of shining white muscovite. This appears in mountain masses and for miles makes the major part of the ridge mentioned above. At the end of the blind road going onto the north end of the mountain it is pseudo-conglomeratic.

Slides cut from the rock at this place were made up of a mass of coarse, limpid, interlocking, unstrained quartz grains which often contain rounded blebs of quartz differently orientated from the host, and probably indicating rapid crystallization. It contains a few blades of muscovite and small triangular tourmalines, zircon, and negative quartz cavities, and large motionless bubbles.

At the south the great mass tapers suddenly to an end in the sharp hill a mile north of the junction of Jack and Keyup brooks. Here it contains some magnetite and biotite. Large veins of later normal pegmatite appear in the rock along the road south of Crag Mountain. The junction of the northfieldite with the Pelham gneiss below is well exposed where it crosses this road north of a house named Sky Farm. Both have a conformable schistosity and easterly dip where they join.

A second great bed of the same border rock appears further north extending into Winchester, and is well exposed along the Ashuelot road skirting Perchog brook on the north and along the next road north where it abuts against the great fault.* The same rock appears predominantly in the hill a mile north of Tullyville where it occupies a circular area a mile across. Another area over three miles long and in places 50 rods wide runs up past Mallard Hill in the east part of Warwick. These seem to be the domes of other similar batholiths which if more deeply eroded would expose a center of the normal Pelham granite.

THE PEGMATITE SCHIST.

The great Crag Mountain band is seen to form a border to the Pelham granite for a long distance and to be divisible into

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* See map, Mon. xxix, U. S. Geo. Sur.

a thick bed of quartzose rock (northfieldite) adjacent to the granite and a thinner upper bed perhaps 50 feet thick of a coarse highly muscovitic pegmatite schist. It is always highly garnetiferous and sometimes the garnets are an inch across, as where the road going east from Sky Farm crosses the band. This dips conformably beneath a sedimentary hornblende schist that passes upward into a clearly sedimentary quartzite and is itself clearly sedimentary, so that for a long time I considered the whole series including the pegmatite schist and northfieldite to be sedimentary. This double band is terminated on the main fault and following that fault south to where it borders the Connecticut at the "French King" near the mouth of Millers River the pegmatite schists appears again along the bank for a mile.

Several of the great pegmatite stocks farther south show in part the same bordering pegmatite schist facies, as at the south end of the great stock just north of New Salem village, described below. Indeed I have mapped a broad band runing from West Orange north through Hockanum Hill as pegmatite, which then passes into a coarse pegmatite schist by loss of its feldspar and continues in a narrow band north for seven miles. On Osgood Brook in Wendell is an oval stock of coarse pegmatite having a border of the same coarse highly muscovitic quartzite. Indeed, the other great pegmatite beds in the region are closely allied with the northfieldite beds here described, and are often in part quite greisen-like.

A few rods west of the highest point in the road east of Mt. Toby in Leverett, just south of which the road to Mt. Toby turns off, one can see the coarse pegmatite grade into a great mass of this coarse quartz rock or northfieldite. It is quite possible that they also may pass downward into a granite like the Pelham and form a pegmatitic phase in the latter, as much of the Hubbadston gneiss further east is a superficial pegmatitic phase of the Fitchburg granite.

The other type of the northfieldite is the rock forming the crest of Mt. Orient in Pelham, where it is 120 feet thick and present in considerable areas in that town and in Shutesbury as a superficial portion of the Pelham granite-gneiss. It contains more than 93 per cent of silica and has the aspect of a slightly actinolitic or biotitic quartzite or an extremely quartzose aplite.

When the gneiss was thought to be an altered Cambrian conglomerate the quartzose upper layer was thought to be the equivalent of the Cheshire quartzite (see Mon. xxix, U. S. Geo. Sur., p. 45). The banking of the gneiss is in a broad arch with low dip to east and west, and the northfieldite forms generally a superficial layer on the gneiss and the transition of the one into the other is perfectly exposed. It is a fine-grained light-colored rock, sometimes quite biolitic and garnet, zircon, rutile and a little feldspar are found in it with the microscope.

The rock in this western area generally contains many minute needles of tremolite or actinolite, but this may be assumed to be from absorption from a former cover which included the thick Bernardston limestone since it is wanting in the eastern occurrences, and since calcite is also found in the neighboring granite in many places. Indeed, two miles north of Mt. Orient a small enclosure of coarse crystalline limestone was found in the northfieldite, and on the contact the latter rock contains much more and coarser actinolite than a few inches away.

At South Leverett mill, south of West Pelham and elsewhere, the actinolite is abundant also in the common gneiss adjacent to the Northfieldite and so is not characteristic of the northfieldite but is derived by both rocks from the limestone which seems to have extended from the Bernardston bed on the north to the limestone bed in Belchertown on the south.

Analyses of northfieldite.

	1	2	3	4	5
SiO_2	93·38	93·20	83·04	80·63	93·48
Al_2O_3	3·09	2·86	6·92	6·22	
Fe_2O_3 FeO	·72	·79	1·34	1·59	
TiO_2	·12	·12	·12	·21	
CaO	·34	·68	3·20	3·69	
MgO	·43	·27	1·98	3·27	
Na_2O	·50	not det.	not det.	not det.	
K_2O	1·32	----	----	----	
P_2O_5	none	none	·04	·02	
	99·90	97·92	96·64	95·63	

1. Northfieldite, Mt. Orient, Pelham, average rock, trace of actinolite. E. T. Allen, analyst.

2. Northfieldite, 60 feet below summit on the west slope and so about 60 feet above trace of biotite. E. T. Allen, analyst.

3. Coarse actinolite-biotite northfieldite. Hollow at east foot of Mt. Orient. In the gneiss. E. T. Allen, analyst.

4. Highly actinolitic northfieldite. Mt. Orient, south face 2–3 feet above base. This contains minute flakes of graphite. It was carefully tested for molybdenum without success by Mr. Allen.

5. Northfieldite, 2 inches from calcite. 2 miles NE. of Mt. Orient. John B. Zinn, analyst.

The norm calculated from the analyses is

Quartz	83·70
Orthoclase	7·78
Albite	4·19
Anorthite	1·67
Hypersthene	1·89
Ilmenite	0·30

According to the C. I. P. W. quantitive classification the northfieldite belongs in class 1 and order 2, but with so large an excess of silica that it almost goes into the unoccupied order 1. It may be expressed: 1. (1)2. 1–2. 3. It is a cardiffose. The difference between analyses 3 and 4 as compared with 1 and 2 depends largely on the presence of actinolite probably due to the introduction of limestone from the cover, and if the analyses be recalculated with the actinolite omitted, 4 agrees closely and 3 approximately with the first two analyses.

In the region of transition from the basic to the acid border beds on the north line of Pelham and two miles north of the type locality on Mt. Orient both border types, the coarse and the fine, are present and present in their normal relations to the subjacent granite gneiss. The northfieldite is present in an area nearly a mile square, as a white fine-grained sugary often friable mass with a little biotite or actinolite. The banking of the gneiss can be seen dipping under it on either side with very low angles. Long bands of a black, rather coarse diorite sometimes banded, sometimes massive, rest upon the northfieldite which dips beneath them from either side. These bands are not very thick and may be assumed to be the remnants spared by erosion of a continuous layer separating the northfieldite from the overlying sedimentary schist into which the great batholite penetrated. It may well have capped the Mt. Orient area to the south, but soon disappeared on the north as the northfieldite is there found in contact with the overlying schists without any diorite band between. Indeed, in Crag Mountain a band of highly muscovitic rock (pegmatite schist) takes its place.

A quartzite like the Crag Mountain rock appears in the lower stage of the Freiberg gneiss, which probably cuts Carboniferous beds, in a thick lens or stock form, sometimes banded and stretched like the adjacent gneiss and contains muscovite and sometimes tourmaline, and rutile. It is thought to be a most acid after-intrusion of the gneiss.*

A similar border bed occurs at Adriaans Kop in So. Africa with 97·43 of quartz† and in Eskdale, England, with 96·43

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* C. Gabert: Die Gneisse des Erzgebirge, und ihre Contact-wirkungen. Zeit. d. Deutschen Geologischen Gesell, vol. lix, p. 322, 1907.

† Iddings, I. P., Igneous Rocks, ii, p. 29, 1913.

SiO_2, as a border to a coarse muscovite biotite granite. It is fine-grained granitoid with only a few flakes of muscovite.* It is suggested in the cited paper that the quartzose border bed represents the surplus of the eutectic which is present in the central granite. It seems possible that the action of a large amount of water upon the superficial portion of the exceptionally acid magma may have promoted the differentiation of this ultra-acid variant much as a pegmatite dike passes into a quartz vein.

A similar highly acid aplitic rock has been found in the border of the Milford granite around Uxbridge. An occurrence one and a half miles north of Millville contained 87·51 per cent SiO_2. It forms a layer of considerable thickness between the normal Milford granite which contains 77 to 78 per cent of SiO_2 and an outer border band of diorite schist.

Amherst, Mass.

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* Dwerryhouse, A. R., Quart. Jour. Geo. Soc., vol. lxv, p. 60, 1890.

SCIENTIFIC INTELLIGENCE.

I. Geology and Mineralogy.

1. *Water Reptiles of the Past and Present;* by Samuel Wendell Williston. Pp. vii, 251, text figs. 1–131. University of Chicago Press, 1914.—In this volume Professor Williston summarizes our knowledge of the reptiles which have become adapted to aquatic life. He also includes a classification of reptiles which differs in several respects from those lately proposed, principally because of the discovery in Europe, South Africa, and North America of so many strange forms which throw doubt on all previous attempts to trace out the genealogies of reptilian orders. The fifth chapter discusses the adaptations of reptiles to aquatic life and the modifications which water-living brings about, comparing the reptiles in their structural changes with other important aquatic types. The following chapters take up the water-loving reptiles in orderly sequence. Professor Williston's books are always interesting and authoritative, and the one under review is no exception to the rule.

R. S. L.

2. *Illinois Coal Mining Investigations.*—The State Geological Survey (University of Illinois) in coöperation with the U. S. Bureau of Mines and the U. S. Geological Survey has recently issued the following Bulletins:

No. 10. Coal resources of District I (Longwall); by Gilbert H. Cady. Pp. 149; 11 pls., 27 figs.

No. 11. Coal resources of District VII (Coal No. 6 west of Duquoin anticline); by Fred H. Kay. Pp. 233; 4 pls., 47 figs.

No. 12. Coal mining practice in District IV; by S. O. Andros. Pp. 57; 23 figs.

3. *Topographic and Geologic Survey of Pennsylvania;* Richard R. Hice, State Geologist.—The following publications have recently been issued: Geologic Map of Southwestern Pennsylvania, Report No. 2. This includes a descriptive pamphlet of 29 pages and a series of 10 plates. Plate I gives the areal and II the structural geology, on a scale of 1/250,000; III is a sketch map showing the location of horizontal sections; IV–X give sections through the various quadrangles involved.

Report No. 7. Engineering Data. Pp. 450; 3 pls.—As a result of the coöperation between the U. S. Geological Survey and the State organization, the topographic survey has now progressed so far that a little more than one-half the State has been mapped. The engineering data accumulated have been brought together in the present volume.

Report No. 8. The Mineral Production of Pennsylvania, 1911. A, Coal and coke; B, Petroleum and natural gas; C, Clay and clay products; D, Copper, nickel, etc.; E, Quarry products, granite, trap rock, sandstone, marble, etc.

4. *West Virginia Geological Survey,* I. C. White, State Geologist. *Boone County;* by C. E. Krebs, Assistant Geologist, and D. D. Teets, Jr., Field Assistant. Part IV. Paleontology; by W. Armstrong Price, Paleontologist. Pp. xviii, 648; 43 pls., 3 figs., 2 maps in pocket, 1915.—Another of the important West Virginia County reports has been added to the series. This report of Boone county contains a detailed description and revision of all the rich coal beds and other geologic formations exposed; the geologic map also gives the structure contours and outcrops of the celebrated No. 2 Gas Coal, and that of several other valuable coal beds, along with many new sections, analyses, etc. The two maps cover the topography and geology of the entire area. Copies of the entire report may be obtained for $2.00; of the geologic map for $1.00, and of the topographic map for 50 cents (address the Survey, P. O. box 848, Morgantown, W. Va.).

In coöperation with the West Virginia Survey, the Bureau of Soils of the U. S. Department of Agriculture has issued the following:

Soil Survey of Boone County, West Virginia; by W. J. Latimer. Pp. 26; 1 fig., 1 map. The same of Logan and Mingo Counties; by W. J. Latimer. Pp. 30; 1 fig. and map.

5. *Wisconsin Geological and Natural History Survey;* E. A. Birge, Director, Wm. O. Hotchkiss, State Geologist.—Recent publications are the following:

Bulletin No. XXXIII. Scientific Series No. 10. The Polyporaceae of Wisconsin; by J. J. Neuman. Pp. 206; 25 pls., 85 figs.—The fungi, described in this report, are of great importance since they are responsible for the decay of numerous valuable timber trees especially in the northern part of State.

No. XXXIV. Economic Series, No. 16. Limestone road materials of Wisconsin; by W. O. HOTCHKISS and E. STEIDTMANN. Pp. 137; 2 figs., 41 pls.

Bulletin No. XLI. Economic Series No. 18. A study of methods of mine valuation and assessment with special reference to the zinc mines of southwestern Wisconsin; by W. L. UGLOW. Pp. v, 73; 12 pls.

6. *Geological Survey of New Jersey*, HENRY B. KÜMMEL, State Geologist.—The following Bulletins have recently appeared: No. 13, on Indian habitations and remains; No. 14, a Summary of the State geology to accompany the geologic map; No. 15, the Mineral Industry for 1913.

7. *Native Silver in Glacial Material at Columbia, Mo.;* by W. A. TARR. (Communicated.)—A fragment of rock found in a small ravine near Columbia, Missouri, by one of the writer's students, Mr. Mayfield Kreutz, proved, upon examination, to consist largely of argentite with an abundance of native silver.

The specimen as originally found, was about $35 \times 40 \times 40^{mm}$ and weighed about 30 grams. The rock is a medium-grained syenite, consisting, aside from the metallic constituents, almost entirely of flesh-colored orthoclase in part kaolinized and bleached in color, with only an occasional, shattered grain of quartz. Disseminated through the rock is a massive black mineral with metallic luster, in irregular masses from several mm. across to minute specks. This was found to be argentite, containing also a small amount of lead, antimony, and arsenic. Intimately associated with it is the native silver; it usually occurs either in the argentite, or more commonly surrounding it. It also forms irregular grains in the feldspar. A very small amount of native copper was detected with the native silver. The silver is most abundant in the bleached phase of the rock. The silver and argentite comprise about 30 per cent of the rock, the argentite greatly exceeding the amount of native silver, there being about 4 to 5 per cent of the latter.

Columbia, Mo. lies near the southern border of the glaciated area. Only one ice-advance reached this region, that being the Kansan. The fragment doubtless owes its present position to this ice sheet. It might be mentioned in this connection that two occurrences of native copper in the glacial material from Northern Missouri have been reported to the writer.

8. *The Mineral Resources of New Mexico;* by FAYETTE A. JONES. Pp. 77; 1 plate and map. Socorro, N. M., 1915.—The state of New Mexico is noted for the variety as well as the extent of its mineral productions; the value of the latter for 1914 aggregated more than $19,000,000. It is also interesting to note that gold was discovered there in 1828, copper mines were opened in 1804, while the turquoise workings, as is well known, go back to pre-historic times. This account of the mineral resources of the state is therefore of particular interest. Its value is increased by the map showing the mining districts and mineral localities.

9. *Geological Investigations in the Broken Hill Area;* by D. Mawson. Mem. Roy. Soc. South Australia, vol. ii, Pt. 4. Pp. 211–319, pls. xxxii. 1912.—The area described extends for 125 miles in an east-west direction on the border between South Australia and New South Wales. The surface consists of ranges of hills with intervening alluvial plains. The rocks exposed are an ancient system of limestones, slates and quartzites together with intrusive acid and basic rocks and a large development of schists and gneisses. Much mineral wealth has been developed amongst the more highly metamorphic rocks. The general structure of the region is that of a highly folded anticlinorium. The sedimentary rocks are Lower Cambrian. Beneath these and occupying the central portion of the area are pre-Cambrian igneous and metamorphic rocks in which the chief mineral deposits lie. In this pre-Cambrian area are granite masses with a profusion of pegmatitic formations which frequently carry ore. The important deposits are argentiferous galena-sphalerite bodies which are thought to have come from an igneous magma by differentiation.
W. E. F.

10. *The Turquoise. A Study of its History, Mineralogy, Geology, Ethnology, Archæology, Mythology, Folklore and Technology;* by J. E. Pogue. National Academy of Sciences, vol. xii, Third Memoir. Pp. 155, figs. 5, pls. 22. 1915.—This memoir, as its sub-title indicates, treats this important gem mineral from a great many view points. That it is exhaustive in its scope and the product of a wide range of investigation is shown by the extensive bibliography given, the titles of which fill 28 closely printed pages. The treatment is very interesting and readable. The numerous illustrations, some of them in color, are excellent in execution and an important addition to the text. W. E. F.

11. *Chiastolites from Bimbowrie, South Australia;* by D. Mawson. Mem. Roy. Soc. of South Australia, vol. ii, Pt. 3., pp. 190–210, pls. xi. 1912.—This paper gives a description of the well-known chiastolites from Bimbowrie, remarkable for their size and structure. The growth of the crystals with the regular arrangement of the inclusions is described and illustrated. W. E. F.

II. Miscellaneous Scientific Intelligence.

1. *Ancient Hunters and Their Modern Representatives;* by W. J. Sollas, D.Sc., F.R.S., Professor of Geology and Palæontology in the University of Oxford. Second edition. Pp. xxiii, 591, 2 plates and 314 text illustrations. London, 1915 (Macmillan & Co.).—The first edition of this work appeared in 1911. The author has made good use of the intervening four years as seen by a comparison of the two. The number and titles (with a single slight exception) of the chapters remain the same; but there are 182 more pages and 80 more illustrations. The new matter is largely due to the consideration of new discoveries such as: *Eoanthropus*, Commont's researches in the Somme valley, the caverns of Castillo, Tuc d'Audoubert, etc. The plan, and this

has not been changed, is perfectly expressed in the title: a comparison of the hunters of the past with those of the present. The most ancient hunters are contrasted with the recently extinct Tasmanians, the Mousterians with the living Australian aborigines, the Aurignacians with the Bushmen, and the Magdalenians with the Eskimo. The comparisons are often carried so far however as to obscure the real merits of the work in the field of prehistory.

The industrial evolution of the last three phases that are distinctly paleolithic is well outlined, including the appearance of new types of stone implements and the use of materials other than stone, such for example as bone, ivory, and the horn of stag and reindeer. The once problematical *bâton de commandement* is believed to be nothing more nor less than a straightener for the shafts of arrows and javelins, as originally suggested by Boyd Dawkins.

In his discussion of *Eoanthropus dawsoni*, recently discovered in a gravel pit at Piltdown common, Sussex, England, the author accepts the views of Dr. A. Smith Woodward and Professor G. Elliot Smith. This briefly is that the skull and lower jaw belong to one and the same individual; that while the skull is "truly human," the lower jaw is "as distinctly simian." Hence the differences between the man of Piltdown and *Homo* are generic, and Dr. Woodward was justified in his use of the name *Eoanthropus*. The canine tooth subsequently found by Father P. Teilhard, Sollas again agrees with Woodward in assigning to the lower jaw, right side (some authorities would place this tooth in the upper jaw instead).

The author has not suppressed his personal opinions on controverted questions. Granting that some of these may be wrong, there is much in the book to commend. With the exception of certain omissions such as failure to mention the old Chellean (or pre-Chellean) camp site of Torralba in Spain, the volume is decidedly up to date. The illustrations though numerous often leave something to be desired in point of execution. The sketch map of the district of Les Eyzies (fig. 81) is antiquated. The insertion twice of the same figure of the mammoth carved in ivory from Předmost, first as a piece of Aurignacian sculpture (fig. 201), and then as representing Solutrean art (fig. 229), is apparently due to an oversight. Figure 168A, representing a mural engraving of the head of a hind, is from Castillo instead of Altamira.

Throughout the book the author's unusual breadth of vision is evident; his power to hold the reader's attention is nowhere relaxed. The new edition of *Ancient Hunters* is perhaps the best work in English covering this particular field.

GEORGE GRANT MACCURDY.

2. *Insects and Man:* An Account of the more important harmful and beneficial Insects, their habits and life-histories, being an Introduction to Economic Entomology for students and general

readers; by C. A. EALAND. Pp. 343, with 16 plates and 100 additional figures. New York, 1915 (The Century Co.).—This book contains an excellent account of the relation of insects to the human welfare. In it the reader will find the most important facts concerning the various groups of insects as destroyers of crops, as carriers of human diseases, as enemies of live stock, as agencies in the control of other insects and pests, as uninvited guests in the household, and as human parasites. There is also an interesting discussion of the general principles of insect control.

The book, treating as it does, of the most important insects without regard to their geographical distribution, will doubtless prove equally valuable to students of economic entomology in any part of the world. It may be cordially recommended to the general reader, for the descriptions of life histories and habits are free from technicalities, many of them being not only interesting but entertaining. W. R. C.

3. *Thirteenth Report on the Sarawak Museum, 1914;* by J. C. MOULTON, Curator. Pp. 48.—This Report of the Sarawak Museum gives an account of the progress on the collections in the different departments. Among the Appendices may be noted a catalogue of the mosquitoes of Borneo, which it is stated reach the number of 92 species, of these 84 have been collected by the Museum. It is interesting to be informed, though the fact is regrettable, that the curator has left the Museum and joined his regiment which has gone to the war.

OBITUARY.

DR. JOSEPH AUSTIN HOLMES, director of the United States Bureau of Mines, died on July 13 at the age of fifty-five years. He was state geologist of North Carolina from 1891 to 1904 and later was engaged in the technological branch of the U. S. Geological Survey. When the Bureau of Mines was established in 1910, he was made the director, and from that time all his energies were given to the development of this department. The results attained in five years were remarkable both in the direction of the conservation of the mineral resources of the country and, still more, in that of diminishing the danger of accidents in mines and saving life when these occurred. The devotion of Dr. Holmes to the latter work involved much personal risk and strain to his health and unhappily resulted indirectly in cutting short a life of rare usefulness to the country.

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THE
AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

Art. XX.—*A Shaler Memorial Study of Coral Reefs;* by W. M. Davis.

Contents:

A Journey across the Pacific.—A liberal grant from the Shaler Memorial Fund of Harvard University, supplemented by a generous subsidy from the British Association for the Advancement of Science with an invitation to attend its meet-

Am. Jour. Sci.—Fourth Series, Vol. XL, No. 237.—September, 1915.
15

ing in Australia during August as a foreign guest, enabled me to spend the greater part of the year 1914 in visiting a number of islands in the Pacific Ocean with the object of testing the various theories that have been invented to account for coral reefs. Thirty-five islands, namely, Oahu in Hawaii, eighteen of the Fiji group, the entire coast line of New Caledonia, the three Loyalty islands, five of the New Hebrides, Rarotonga in the Cook group, and six of the Society islands, as well as a long stretch of the Queensland coast inside of the Great Barrier reef of northeastern Australia, were examined in greater or less detail. Darwin's theory of subsidence, invented when he was twenty-five years old and before he had ever seen a true coral reef, is in my opinion the only theory competent to account for the coral reefs that I visited, because it is the only theory that will also reasonably account for the features of the encircled volcanic islands; thus my work leads to the same conclusion as that reached by several other recent students of this old problem.

The longer voyages between island groups and the shorter excursions among the grouped islands were accomplished much more easily than I supposed would be possible. Many attentions from officials and from merchants, as well as from natives, added an unexpected comfort in far distant places. An abstract of results has appeared in the Proceedings of the National Academy of Sciences for March, 1915, in Science for March 26, and in Nature for April 15, 1915. A full discussion of my observations will be published later, probably in the Bulletin of the Museum of Comparative Zoology at Harvard College. A statement of the chief results gained here follows.

Theories of Coral Reefs.—Before setting out on the voyage, I reviewed various theories of coral reefs in an essay that was published during my absence under the title of "The Home Study of Coral Reefs" in the Bulletin of the American Geographical Society for 1914. The theories there discussed were carefully considered while I was on various Pacific islands with particular reference to the deduced consequences as well as to the initial postulates by which each theory is distinguished from its fellows. In this connection it is important to recognize that every one of the several theories proposed to account for coral reefs is successful in explaining the visible features of sea-level reefs themselves, provided the postulated conditions and assumed processes of the invisible past are accepted. Evidently then a study of existing sea-level reefs alone will not suffice to discover which theory really provides a correct mental counterpart of their earlier and unobservable history. I repeatedly took occasion to test the truth of this statement while wading upon a well-formed barrier reef, beaten by the surf on its exposed front, swept over by the foaming surge, and backed by the quieter waters of the lagoon. As far as the facts there visible are concerned, a coral reef may be the result of upward or outward growth from a still-standing foundation, as Murray supposed; it may be merely a veneer on the outer edge of a wave-cut platform, as Agassiz thought; or an upward growth from submarine lava-flows, as Guppy suggested; it may have been formed by upward growth during the rise of sea level as the continental ice-sheets of the glacial period melted, the upward growth having been begun on the outer edge of a platform down to which preglacial reefs were abraded by wave action while the sea level was lowered by the withdrawal of water to form continental ice-sheets, and while the corals of the reefs were killed by the lowered ocean temperatures of the glacial period, as Daly has recently argued; it may have been formed by upward growth around a slowly subsiding island, as Darwin long ago believed. Sea-level coral reefs, taken alone, do not afford any sufficient test by which the true theory—that is, the correct mental counterpart of the unobservable facts of the past—can be detected. Hence appeal must be made from the non-committal sea-level reefs to competent witnesses of some other kind, which were present while the reefs were forming and which are willing to testify about the events which then took place. The testimony of such witnesses will be presented in terms of the changes which they themselves suffered during the growth of the reefs; and these changes, if still recognizable, ought to supply evidence as to the conditions and processes under which the near-by reefs had their origin. The evidence thus secured should contradict all the erroneous theories and confirm the correct one.

Evidence derived from Barrier Reefs.—In searching for such witnesses it should be borne in mind, first, that as far as fringing reefs, A, A, A, fig. 1, are concerned, their origin is hardly in debate: they are growing colonies of corals, initiated by the arrival from elsewhere of passively floating larvæ which establish themselves in shallow water close around a newly offered and suitable reef-free shore line under fitting conditions of temperature; the reef thus formed being afterwards enlarged by upward or outward growth without other important change; second, that as far as atolls—or reef-rings enclosing shallow lagoons—are concerned, they are inscrutable unless penetrated by numerous and expensive borings, for they stand alone and bury their past; third, that as far as elevated reefs are concerned, their inner structure and their relation to the foundations on which they were formed will give important evidence regarding their origin, and should therefore be investigated; and fourth, that it is in connection with barrier reefs, B, B, B, fig. 1, that the desired witnesses to the facts of the past can be most readily found; for the central island, rising from the lagoon within a barrier reef, was surely there while the reef was forming around it, and the features of the island shoreline will, as Darwin long ago showed for still-standing islands and as Dana a few years later pointed out for subsiding islands, afford critical evidence regarding the changes which the island suffered contemporaneously with the formation of the encircling reef. By means of such evidence it should be possible to exclude certain theories with which the changes suffered by the central island are inconsistent, and to substantiate any theory, the logical consequences of which include the changes suffered by the central island quite as necessarily as the formation of the reef itself. These considerations may make it clear why my work has been almost wholly confined to the central islands of barrier reefs, though several examples of uplifted reefs were not neglected.

Fig. 1.

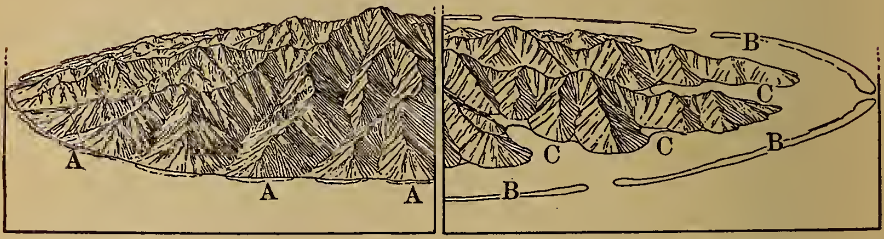

Fig. 1. Fringing and barrier reefs.

Coral Reefs on still-standing Islands.—The various theories of coral reefs may be divided into two groups. Those of the first group, some six or seven in number, postulate a fixed relation between land and sea level during the development of the reefs: these will be called the still-stand theories. The two theories of the second group postulate a change in the relative level of land and sea during the development of the reefs. As far as the barrier reefs that I have visited are concerned all the theories of the first group must be rejected, because within every one of these barrier reefs the embayments or drowned valleys, C, C, C, fig. 1, by which the shoreline of the central volcanic island is indented, give indisputable evidence of recent change of level, of such a kind that the sea has gained on the land. This conclusion evidently postulates that the depressions now occupied by embayments originated as valleys of subaerial erosion, which can be excavated only above sea level, and not as sunken fault blocks, which are not definitely related to sea level; but on this point the form of the valleys and their branches, upstream from the bayheads, leaves no doubt whatever.

I believe that the same conclusion applies to all barrier reefs, first for the reason that those which I visited were not selected because they were thought to be in any way unlike other members of their kind, but because they were easily accessible; and second, because all the charts of other barrier reefs that I have examined show that they also have central islands with embayed shorelines. For none of these islands can any one of the still-stand theories hold good.

Contrast of Cuban and Pacific Reefs.—It is, however, worth noting that the embayments here considered have a quite different relation to the adjacent coral reefs from that found, according to Hayes, Vaughan and Spencer, in the pouched-reef harbors of Cuba: all the embayments that I saw inside of sea-level barrier reefs in the Pacific islands occupy valleys that are older than the reefs; but in Cuba the valleys, and still more the subsidence which drowned them in producing the pouched harbors, are described by the above-named authors as younger than the elevated reefs which enclose them; and such valleys do not bear on the origin of the reefs, as appears from the following extract:—"The depressions occupied by the water forming these harbors appear to be due entirely to erosion by streams flowing into the sea during a recent geological period when the land stood somewhat higher than now. In other words, they are drowned drainage basins. Their peculiar shape, a narrow seaward channel and a broad landward expansion, is due to the relation of hard and soft rocks which generally prevail along the coast. Wherever the conditions are favorable for the growth of corals a fringing reef is built upon whatever rocks happen to be at sea level, and as the land rises or sinks this reef rock forms a veneer of varying thickness upon the seaward land surface. The rocks on which this veneer rests are generally limestones and marls much softer and more easily eroded than the coral rock. Hence several small streams, instead of each flowing directly to the sea by its own channel, are diverted to a single narrow channel through the hard coral rock, while they excavate a basin of greater or less extent in the softer rocks back from the coast." It is briefly explained on a later page that the elevated reefs now stand at an altitude of 30 or 40 feet; that their formation was associated with a subsidence of from 80 to 100 feet, and one may infer that they were then formed during this subsidence, although no direct statement to that effect is made; that an elevation of similar amount then occurred, during which the valleys of the harbors were eroded; and still later a subsidence of from 40 to 70 feet, when the valleys were drowned and the harbors were formed.*

A somewhat different explanation of the Cuban harbors was given nearly twenty years earlier by W. O. Crosby, who wrote:—"Every harbor is at the mouth of one or more rivers, and their inlets, as I conceive, are the work, not of the sea, but of rivers at a time when the land was higher than now . . . . The main body of the harbor, in each case, is simply the broader and older portion of the river valley behind the barrier reef, which has been invaded by the rising sea. . . When the reef was finally raised to something above its present level each river . . . cut a narrow channel through the reef itself," and then subsidence drowned the reef channel.† In both these explanations, it is tacitly assumed that the reefs were continuous when formed. A simpler explanation of the Cuban harbors, and one that does not include this improbable assumption, has been suggested by R. T. Hill, to the effect that "the narrow outlets through the reef rock . . . are channels representing originally areas of non-coralline growth, such as are now known to exist in submerged [non-elevated] reefs . . . and such as biological laws tell us should exist opposite the mouths of rivers."‡ Without additional field study it is impossible to say which one of these views is correct; but the features of the Pacific reefs that I have seen support Hill's explanation.

Value of Physiographic Evidence.—To zoologists who are not familiar with the evolution of shorelines or with the inferences that can be drawn from them as to recent or subrecent changes of level, it may seem presumptuous to attach so much importance to physiographic evidence as the second preceding section gives it, in a problem that has usually been treated from its zoological side; but to physiographers who are acquainted with the modern progress of their science the value of this evidence will be more manifest. It may nevertheless seem even to them over-bold thus at a stroke to sweep away all the stand-still theories, and so indeed it would be if the postulate of a still-stand were an unessential element of these theories; but as a matter of fact it is a fundamentally essential element, gratuitous as is the supposition of an ocean bottom that can rise but cannot sink; for the stand-still theo-

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* C. W. Hayes, T. W. Vaughan and A. C. Spencer. Report on a Geological Reconnoissance of Cuba . . . [Washington ?] 1901; see pp. 17, 23, 34.

† On the elevated reefs of Cuba, Proc. Boston, Soc. Nat. Hist., xxii, 1884, 124–130; see pp. 128, 129.

‡ Notes on the Geology of the Island of Cuba. Bull. Mus. Comp. Zool. xvi, 1895, 243–288: see p. 279.

ries were in nearly all cases proposed to replace Darwin's theory of subsidence. So again would it be over-bold at once to reject all the stand-still theories if their inventors had duly considered the embayed shorelines of the volcanic islands within barrier reefs, and had thereupon said:—"Truly these embayments look at first sight as if they had been produced by a departure from the postulated still-stand of the central island, whereby the distal parts of previously eroded valleys have been submerged; yet as a matter of fact the embayments are not the result of submergence, but of" . . . . some other process. Unfortunately, however, no sufficient attention has been given to the embayed shorelines of the central islands in any discussion of the stand-still theories: their investigators have passed silently over these significant features as if they had no bearing on the problem at issue.

Dana's Principle of Shoreline Development.—Such neglect of a really essential factor is all the more surprising when it is remembered that as long ago as 1849 the embayment of the central islands of barrier reefs was shown by Dana in the clearest and most emphatic manner to follow as a necessary consequence from Darwin's postulate of subsidence; for it was Dana who first, when he was on the Pacific ten years earlier, recognized that the subsidence of a dissected land surface must produce an embayed shoreline.* He discovered this important principle—"Dana's principle of shoreline development," as it may be called—and recognized its value as an independent confirmation of the theory of subsidence, when he crossed the Pacific about four years after Darwin, as he was to a day four years Darwin's junior. It is surprising also that the logical value of Dana's principle in giving independent confirmation to Darwin's theory was recognized by so few of the many geologists who accepted Darwin's theory, and never by Darwin himself; and it is certainly disappointing, from the viewpoint of disciplined scientific investigation, to see that many geologists, who had been brought up on Darwin's theory, later abandoned it for one or another of the stand-still theories against which Dana's principle offers immediate and incontrovertible evidence as far as barrier reefs are concerned, and very strong presumptive evidence in the case of reefs of other kinds as well; for it is unreasonable to suppose that a change in the relative level of land and sea should occur only in regions where the central islands of barrier reefs are present to attest it, and not in neighboring regions where reefs of identical form but without a central island are given the name of atolls. Whether any existing atolls have been built up from still-stand-

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* Dana's Confirmation of Darwin's Theory of Coral Reefs, this Journal, xxxv, 173, 1913.

ing submarine foundations rising from a fixed ocean bottom, as Murray supposed, is beyond direct proof without the aid of numerous expensive borings; but the facts that barrier-reef islands everywhere show signs of submergence, and that many fringing reefs, barrier reefs and atolls have been elevated, strongly suggest that the ocean bottom is not fixed, and that still-standing foundations must be of rare or impossible occurrence.

It is not a little interesting to learn that—exception being made of work very lately published—the only observers of coral reefs who have applied Dana's principle regarding the embayment of dissected coasts to the coral-reef problem in the Pacific are Australasians, a fact to which I had the pleasure of calling attention at the Sydney meeting of the British Association in August, 1914. E. C. Andrews was in 1902* the first to adduce the embayment of the Queensland coast in evidence of recent submergence, one consequence of which he saw to be the upgrowth of the Great Barrier reef; C. Hedley and T. G. Taylor† followed with additional details a few years later, and P. Marshall made a more general application of the same argument in 1912.‡ In 1914 T. W. Vaughan§ stated that recent submergence, indicated by embayed shorelines, is characteristic of several West Indian islands, more or less encircled by barrier reefs: this is the most general statement of the kind that I have found concerning Atlantic reefs.

Out-growing Reefs on still-standing Islands.—Before considering the theories of the second group, it is desirable to state more directly the chief reasons against two theories of the first group which have gained prominence within the last three decades. The theory that explains barrier reefs as the result of outgrowth of fringing reefs on their own advancing talus, while the lagoon behind them is excavated by solution around the still-standing central island, has since 1880 received widespread attention, because it was then announced by an oceanographer of so wide experience as Sir John Murray. It is significant that Murray had been, a few years before as a member of the "Challenger" staff, on the wonderfully embayed island of Kandavu in the Fiji group, and that the Narrative Report, to which he presumably contributed, made no special mention of the embayments and no mention whatever of their

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* Preliminary Note on the Geology of the Queensland Coast; Proc. Linn. Soc. N. S. W., xxvii, 146–185, 1902; see p. 183.

† Coral Reefs of the Great Barrier, Queensland; Proc. Austral. Assoc. Adv. Sci., ii, 397–413, 1908.

‡ Oceania, pp. 7, 30, in Vol. vii, Abt. 1, Heft 5, of Steinmann and Wilckens Handbuch der regionalen Geologie, Heidelberg, 1912.

§ The platforms of barrier reefs, Bull. Amer. Geogr. Soc., xliv, 1914, 426–429.

manifest origin by submergence, although "indications of recent elevation" in the form of high-water marks a few feet above tide level are described.* Naturally enough, then, no consideration of submergence is found in his theory of coral reefs.

This theory is inapplicable to any of the barrier reefs that I have seen, (1) because the embayments of the central island, as in sector O, fig. 2, prove that the relative level of land and sea has changed, as already stated; (2) because deltas advancing beyond the outer margin of the non-embayed central island into the lagoon, sectors H, J, K, as they should if the island had stood still, are conspicuously absent in all but two of the barrier-reef islands I have visited, although deltas of moderate size are always to be found in the bay heads; (3) because the lagoons, far from suffering excavation from solution, seem to be receiving new deposits by overwash from the outer reef, by outgrowth of inner fringing reefs, by inwash from stream deltas, and by organic growth on the lagoon floor; (4) because uplifted reefs, as far as known, do not show, as at M, the steeply inclined talus-stratification resting on non-eroded volcanic beds, as they should under this theory; (5) because no barrier reefs are known in which the central volcanic island is worn down to a lowland within a delta plain, as in sector K, and because no almost-atolls are known in which the residual central islands are vanishing lowland remnants, as in sector L; although both these forms should occur if, as Murray briefly

Fig. 2.

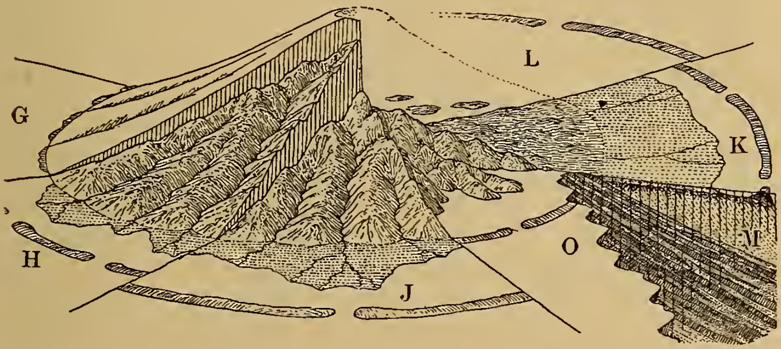

Fig. 2. Deduced stages, sectors G to L, of an outgrowing reef on a still-standing island; sector O, observed features of a barrier reef island.

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* Challenger Reports: Narrative, i, 508, 1885.

suggested, barrier reefs are converted into atolls by the wearing away of the central islands.

The two islands which have deltas advancing into their lagoons are both large: one is Viti Levu, the largest of the Fiji group, where certain rivers of a considerable volume and of greatly increased flow after heavy rains have built their deltas forward, outside of the general outline of the island; the other is Tahiti, the largest of the Society group, where a present still-stand, recognized by Darwin as well as by Murray, is attested by a belt of alluvial flats and deltas that is more or less continuous around the island; but recent subsidence is well proved for both these islands by the form of their delta plains, which head between advancing spurs in strongly reëntrant spaces that were assuredly drowned-valley embayments before the deltas filled them. New Caledonia might be added as a third example of a large barrier-reef island which possesses good-sized deltas, but the deltas there are as a rule contained in the embayments and do not yet extend beyond the partly drowned headlands by which the embayments are bordered. Large deltas are similarly situated between the headlands of the embayed Queensland coast. Submergence unquestionably preceded delta formation in all four of these examples.

Reefs as Veneers on Wave-cut Platforms.—The explanation of barrier reefs as relatively thin veneers on the outer edge of wave-cut platforms around still-standing islands, was long ago suggested by Tyerman and Bennet (quoted by Darwin) and afterwards advocated by Guppy and Agassiz; it was extended by Wharton to the explanation of atolls, by supposing that in such cases the volcanic islands were completely truncated before corals were established on the resulting platform. The explanation is not satisfactory (1), because, as already stated, the occurrence of drowned-valley embayments in barrier-reef islands shows conclusively, as in sector O, fig. 3, that the relation of land and sea level has changed; (2) because the prevailing absence of sea cliffs, sectors H, J, around central islands, negatives, as Darwin long ago pointed out, the occurrence of a sea-cut platform of significant width; (3) because the depth of many lagoons is greater than that of wave-cut platforms of the same width; (4) because no almost-atolls are known in which the residual central island is a cliff-rimmed stack, as in sector K′; (5) because no sufficient reason has been found to explain the delay in the establishment of reefs, as here required, while a broad platform was abraded; (6) because no uplifted reefs have been found in the form of relatively thin veneers on the outer edge of broadly abraded rock benches, as in sections H′ and J′. It is, however, true that nearly all the spur ends of the submaturely dissected cone of

Tahiti are truncated by cliffs, some of which are several hundred feet in height: and that much of the northeastern side and all of the southeastern end of New Caledonia are strongly cliffed; but in both of these exceptional cases, the mature valleys by which the cliffs are interrupted must have been eroded during a relatively long period when the islands stood higher with respect to sea level than they do to-day, and in the relatively short period since then the valleys have been submerged, embayed, and more or less filled with delta plains. The erosion of the cliffs also must have required a relatively long period of time, and therefore must have taken place while the islands stood higher than now; hence the base of the cliffs also must have been submerged. The existing barrier reefs of these two large islands must have grown upward during the submergence, in a manner very similar to that in which barrier reefs elsewhere have grown up during the submergence of noncliffed central islands. Why these two large islands were so strongly cliffed before reefs were formed around them is a problem to which I shall return in my detailed report, though not with great confidence of solving it successfully.

Fig. 3.

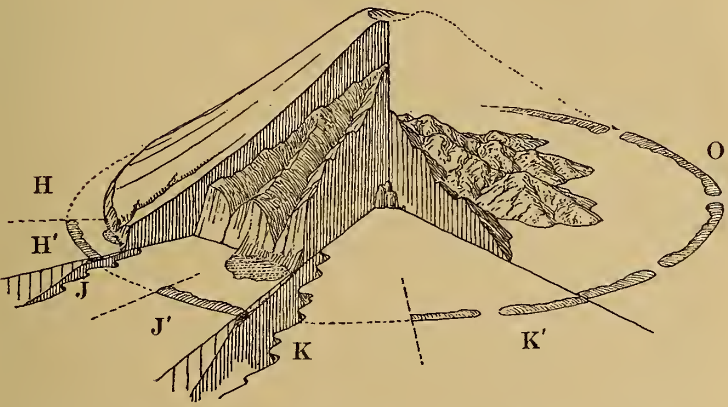

Fig. 3. Deduced stages, sectors H to K, of a veneering reef on a wave-cut platform; sector O, observed features of a barrier-reef.

The Continental Shelf of Australia and the Great Barrier Reef.—Before leaving this explanation of our problem, it should be pointed out that Guppy, in 1890, brought to its support the continuity of the continental shelf, or "submarine ledge" as he called it, along the eastern coast of Australia, from the Great Barrier reef farther southward for a thousand or more miles. After a careful study of all soundings then available he concluded that a platform, "cut out in the course of ages by the action of the sea," flanked the entire coast before the reef was formed, and that the reef has been built up near the edge of its northern part,* where the ocean is warmer, but without submergence. No reason is given for the change from destructive abrasion to constructive reef building.

The abundant embayments and the rare cliffs of the Queensland coast, and the numerous off-shore islands that rise in submountainous form with embayed coasts, little cliffed, in the lagoon of the Great Barrier reef are, as Andrews, Hedley and Taylor have shown, sufficient to disprove the supposition that the part of the platform which they surmount is due to marine abrasion without submergence; and the consensus of opinion among geologists would, I believe, be strongly against regarding the continental shelf farther south along the Australian coast as a surface of abrasion alone, without submergence, rather than as a surface of limited abrasion combined with abundant deposition, followed by submergence. Hence Guppy's explanation of the Great Barrier reef without submergence seems to me untenable.

Reefs and Reef Platforms.—A platform theory for barrier reefs has lately been proposed by Vaughan, who regards recent submergence, proved by the embayments of the central islands, as the determining cause for the upgrowth of existing barrier reefs, but who interprets the deeper and larger part of the entire reef-mass as a "platform" of earlier origin, independent of coral formation.† As this investigator has not yet published his views regarding the origin of the reef platforms, his general theory will not be here discussed further than to note that it seems inadmissible for many barrier reefs in the Fiji, Society and other groups, in which the total thickness of the reefs appears to be much greater than the depth of the "platforms"; that the occurrence of certain discontinuous barrier reefs on a submarine platform, as instanced by Vaughan, seems to be explicable by the hypothesis that the platform represents a rapidly submerged reef which had been broadened during a pause or still-stand after an earlier long-continued submergence, and that the present discontinuous reef has grown up imperfectly during the recent and rapid submergence that drowned its predecessor. Like Guppy, Vaughan points to the extension of the continental shelf along the east coast of Australia, south of the Great Barrier reef, and infers from this

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* H. B. Guppy, "The Origin of Coral Reefs," Trans. Victoria Inst., xxiii, 51-61, 1890.

† Sketch of the Geologic History of the Florida Coral Reef Tract, Journ. Wash. Acad. Sci., iv, 26-34, 1914; see p. 33. "The Platforms of Barrier Reefs," Bull. Amer. Geogr. Soc., xliv, 426-429, 1914.

that a continental shelf of one origin extends along the whole coast; but unlike Guppy, Vaughan recognizes the submergence that the coast has suffered, and explains the Barrier reef as having grown up only on the warmer, northern part of the shelf—the Queensland border—during and after submergence. On this point the following comments are offered:

As far as the shelf south of the reef—along the New South Wales border—is concerned, it may well be the result of inorganic marine processes of abrasion and deposition during a long still-stand period before the recent submergence of the continental margin; during the same still-stand period, indeed, as that in which the Queensland coast was, as Andrews has shown, worn down to a lowland. There is good reason for supposing that the still-stand period was preceded by flexure, which uplifted the interior highland belt and depressed the coastal margin and the adjoining belt of the sea floor; and if so, it is reasonable to suppose that then, as now, the warmer sea-floor belt was, during and after submergence, the seat of an upgrowing barrier reef, which in the later stages of the same still-stand period was broadened by lateral growth, just as the present barrier reef is now broadening; and that still later the lagoon was filled with coral sand from the reef, with organic deposits of local origin, and with land waste from the coast. Thus a great terrace-like rampart—the total mass of the coral reef, in the large sense of that term—was added to the Queensland border, in such form that, although above instead of below water, it imitated in a general way the form of the inorganic shelf farther south; for surely there is no sufficient reason for doubting that coral reefs could be formed along the Queensland border before the recent submergence just as well as afterwards. The chief differences between the northern and southern—the Queensland and the New South Wales—parts of the shelf before submergence would have been determined, as they are now, by the presence of the Barrier reef. Where it grew, the exterior marine agencies could work only on the breakwater formed by its organic mass, while farther south they could work on all the shallow sea bottom and on the edge of the continent as well. There they must have abraded a shallow platform along the shore, and carried out the detritus thus derived, as well as that received from the rivers, to build the outer border of the shelf. In both parts of the shelf there must have been large deposits of land waste brought down by rivers, just as there is to-day, because the coast of both parts rises rapidly inland to a well-watered highland. The occurrence of such detritus in abundance is expectable in an inorganic continental shelf formed along a still-standing coast of rather strong relief long subjected to erosion; it is none the less expectable in the total mass of a coral reef rampart, formed along a similar coast in warmer latitudes. Therein, indeed, must lie one of the chief contrasts between the total reef mass of a continental border and the total reef mass around a small oceanic island. The contrast might be so great as to warrant different names for the two structures; but whatever the nomenclature of the problem, it is reasonable to suppose that a barrier reef was the distinguishing feature of the Queensland border in the long still-stand period before the recent submergence, just as it is in the present period after the submergence. Hence, it seems to me unreasonable to conclude, without decisive evidence, that the Queensland border had no barrier reef while the continental shelf was forming along the border of New South Wales.

Coral Reefs and the Glacial Period.—It remains to inquire which one of the theories that postulate a change in the relative level of land and sea best accounts for the facts of barrier reefs and their associated central islands. One of these is Darwin's simple theory of a slowly subsiding ocean bottom, as a result of which the islands that stand on the ocean bottom gradually sink, diminish in size, and eventually disappear, while their fringing reefs grow upwards and are converted into barrier reefs and atolls. The other is the more complicated "glacial-control theory," independently suggested by Belt and by Upham some years ago, briefly discussed by Penck in 1894, and lately elaborated by Daly* with especial reference to atolls. It begins, as above stated, by assuming essentially still-standing foundations, above and around which outgrowing atolls of less or greater size, standing near sea level, A, fig. 4, with shallow lagoons or none, were developed in preglacial times; a lowering of sea level is then inferred during the glacial period, when a significant amount of sea water was withdrawn to form the continental ice sheets, and when in consequence of lowered ocean temperature the corals of most reefs were killed; next follows an abrasion of the undefended preglacial reefs by wave attack on their flanks so as to reduce them to flat platforms, D, a little below the lowered sea level; and finally, when a rising temperature melts the continental ice-sheets and the sea surface is raised and warmed, and the corals are permitted to grow again, reefs are built up to the present sea level, E, around the margin of the abraded platforms, producing barrier reefs or atolls. A critical discussion of this theory would require a consideration of the several glacial and interglacial epochs into which the glacial period as a whole is divided, but I shall here follow Daly in using only the general term, glacial

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* Pleistocene Glaciation and the Coral Reef Problem, this Journal, xxx, 297–308, 1910.

period, and in not considering successive depressions of sea level separately, although it must of course be understood that several oscillations of sea level must have taken place.

Under this theory the smooth floor of a large lagoon is regarded as preserving with little change the flat surface of the platform abraded during the lower stand of the sea; and the embayments of the central islands within a barrier reef are explained as drowned valleys that were eroded while the sea level was lowered. Like all the other theories of coral reefs, this one will account for the visible features of the reefs themselves, if its postulates and processes are accepted. The postulate of changes in the level of the sea during the glacial period seems undeniable; but as recently set forth the theory includes, on what seem to be unproved, hypothetical grounds, the unessential assumption of a practically never-subsiding ocean bottom; for Daly writes:—"There is no reason to doubt that the volcanoes [of the Pacific] here considered are of many different ages, possibly from the pre-Cambrian to the Tertiary. For the older ones, subaerial denudation must have . . . approached or reached peneplanation. . . . Such denudation, combined with marine erosion during pre-Pleistocene time, had reduced most of the volcanic masses to the plateau form" (304); and it is on such platforms that atolls are supposed to stand, although not one of several uplifted atolls shows any trace of such a platform. Thus the theory really belongs with the still-stand theories already considered, as far as the stability of the ocean bottom is concerned, and therefore stands in unnecessary opposition to Darwin's theory of subsidence, instead of, as appears to me more reasonable, working in coöperation with it.

Our knowledge of ocean basins is by no means sufficient to warrant the assumption that the ocean floors have been so steady through Paleozoic, Mesozoic and Cenozoic time as to allow the subaerial erosion and abrasion to truncate the cones of pre-Cambrian or Paleozoic volcanoes and thus produce shallow platforms, on which the depth of water has changed only as the climate of the glacial period changed the level of the ocean surface. If some truncated cones had been revealed by uplift, it would be easier to imagine that other cones, similarly truncated, served as the foundations for hundreds of atolls; but, as above stated, not a single example of a truncated cone has been observed in the coral seas.

Again, it is not reasonable to assign the special value, zero, to a process like ocean-floor subsidence, of which we know so little, particularly in an ocean which contains many uplifted reefs, still more in an ocean which in its western part, where coral reefs are most abundant, contains several islands of continental rocks, the extent of which has unquestionably been decreased by subsidence in the later geological ages.

Furthermore, the " remarkable flatness " of the platforms on which it is supposed that the existing reefs have been built, and "their nearly uniform depth of 45 to 50 fathoms," are conclusions which, I believe, are not supported by Daly's table of lagoon depths. Measures for the 60 lagoons there listed do not show that their floors have remarkable flatness, for, in the first place, the " maximum depth " of a lagoon is often 20 or 30 per cent, and sometimes 60, 80, or 100 per cent greater than the " mean depth in deeper part," hence the depth is by no means uniform in single lagoons; in the second place, the "mean depth in deeper part " varies from 20 to 40 fathoms, that is, by double its smaller value, hence the mean depth is not at all uniform from lagoon to lagoon ; and in the third place, the " maximum depth " of different lagoons ranges rather equably from 26 to 37 fathoms, and in six cases it is less than 25 fathoms ; in only about one-fifth of the 60 lagoons is the maximum depth 45 fathoms or more ; hence a depth of " 45 to 50 fathoms " is distinctly exceptional. These figures do not give, to my reading, sufficient ground for citing " the smoothness of the plateaus " and " their steady adherence to the average depth of about 45 fathoms " (302) as evidence against either the Darwin-Dana hypothesis of prolonged subsidence, or the Murray hypothesis of solution. To be sure, if it be assumed that smooth platforms of whatever origin exist at depths of 45 or 50 fathoms beneath the actual lagoon floors, it is conceivable that the upgrowth of reefs near their margin and the accumulation of lagoon deposits over their surface might give the actual lagoons the large inequalities of depth (large in proportion to their mean depth) discovered by soundings ; but the soundings of Daly's table give no sufficient warrant for such an assumption. As to the relation of the depth of the embayments in barrier-reef islands to the glacial lowering of sea level, I cannot accept the statement that " the Pleistocene deepening of the inter-tropical seas is precisely of the amount required to explain the drowned valleys of the volcanic islands which are now surrounded by barrier reefs" ; for the depth of the embayments has been diminished by sedimentation : in Tahiti and in the largest islands of the Fiji group, Viti Levu, and Vanna Levu, the embayments are in large measure converted into delta plains; the depth of their rock bottom is unknown ; even in smaller islands some filling must have taken place, because deltas are advancing at the bay heads and fringing reefs frequently contribute much detritus near bay mouths. It will be shown later that some of the embayments are probably filled with sediment and sea water to a depth of 600, 800 or perhaps 1000 feet. But before taking up that question, further inquiry must be made into the possible origin of lagoons by the abrasion of preglacial sea-level reefs.

Lagoon Floors are not Wave-cut Platforms.—Consider the case of a narrow-lagoon barrier reef, C, fig. 5. If the floor of such a lagoon, half a mile or a mile wide, represents as much work as marine abrasion can accomplish in reducing a dead, preglacial reef, A, to a smooth platform, B, during the lowered sea-stand of the glacial period, it follows that the lagoon-floor of a large reef, such as that of Hogoleu (or Truk) in the Carolines, 34 miles in diameter, cannot be of the same origin; still less could any large part of the vast lagoon of the Great Barrier reef of Australia, sometimes 70 or more miles wide, be due to marine abrasion during a lowered sea-stand, for it could have been attacked by the waves only on one side. So large an atoll as Hogoleu should preserve the central tabular part, B, fig. 4 (more dissected than here drawn), of its preglacial reef-limestone plain, A, standing practically at sea level and surrounded by an abraded lagoon-floor a mile or so wide, outside of which a barrier reef, C, should rise to-day. No such central limestone table is known in any atoll. If, on the other hand, the floor, D, fig. 4, of a wide lagoon, E, like that of Hogoleu, or of the Great Barrier reef of Australia, represents the abrasive work of the lowered and chilled sea acting on a preglacial reef-plain, A, during the glacial period, then not only the whole width of a narrow preglacial encircling reef, A, fig. 5, ought to be cut away, as at B, but cliffs, D, D, truncating the spur ends, should have been cut all around the margin of the central volcanic island as well, and after the barrier reef is built up in the rising sea the spur-end cliffs should rise from the postglacial lagoon, E. This would appear to be Daly's view for many islands, for he writes: " The undefended islands,

Fig. 4.

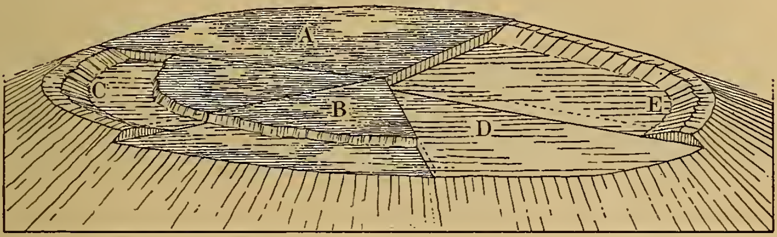

Fig. 4. Deduced stages of an atoll, according to the glacial-control theory.

largely composed of relatively weak volcanic and calcareous materials, must . . . yield extensively to the waves, which as a rule ran in from very deep water on every side and thus, with special power, attacked the islands" (304); he adds, however: "The lava-formed islands of late Tertiary or Pleistocene dates . . . would stoutly resist abrasion" (305). But cliff-rimmed central islands are not known, with the exception of New Caledonia and Tahiti, as stated above, and Tahiti

FIG. 5.

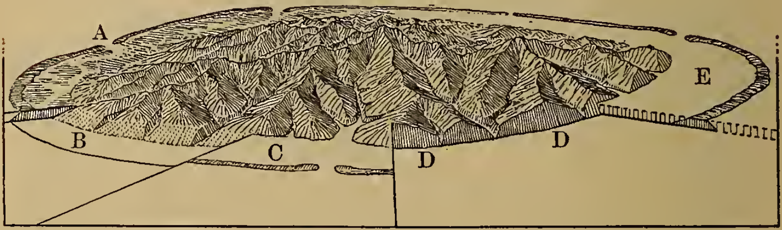

FIG. 5. Deduced stages of a barrier reef, according to the glacial-control theory.

is a "lava-formed island," which Daly places with those that should "stoutly resist abrasion." [No account is here taken of certain islands in which two or three spurs are cut off in cliffs, while twenty or thirty are not cut off: these will be considered in my detailed report.] Hence it appears impossible to explain both wide and narrow lagoons by the theory here under consideration. Escape from this dilemma may be found by assuming that the corals of narrow-lagoon barrier reefs were not killed by lowered ocean temperatures so soon as those of wide-lagoon atolls: but this assumption is too arbitrary to be acceptable. Hence, as far as these two lines of evidence go, it must be concluded that the corals were generally not killed during the glacial period, and that lagoon floors are generally not abraded platforms.

The Valleys of Barrier-reef Islands.—Furthermore, if the embayments of a central island within a barrier reef result from the drowning of valleys that were eroded with respect to the lowered sea level, B, fig. 5, of a relatively short glacial period, then each such valley must be entrenched in the floor of a preglacial valley; and above the head of each embayment resulting from the drowning of a new-cut valley, there should be a "valley-in-valley" landscape, as in sector C, unless the preglacial valley was so young and narrow that its sides were undercut and destroyed by the deepening and widening of the glacial valley. This special condition might obtain on some islands, but not on all; yet in no case that came under my observation were the embayments continued inland by "valley-in-valley" forms of two-cycle origin. Every embayment that I saw—and their total number must be many hundred—occupied merely the submerged distal part, C, C, fig. 1, of a maturely-opened, one-cycle valley or valley system, of which the branching heads reached up to the mountain crest without any indication of revival by a relative depression of baselevel. In no case was a narrow incised valley prolonged upstream from a bayhead, as should happen if the lowered sea-stand had not endured long enough for the waves to cliff the spur ends; and it must not be supposed that the incised valley is filled again with alluvium, for that result could not be reached until the whole bay is filled with a delta plain, sloping at the same angle as the preglacial floor.

If it be supposed, on the other hand, that the glacial period was relatively long, then the deepened valleys might have everywhere been widened so far as to destroy all traces of preglacial forms; but in this case again the spur-ends of narrow-lagoon islands must have been truncated in wave-cut cliffs, D, D, fig .5. The assumption that the sea would have time to cut cliffs around a narrow-lagoon central island while the small-stream valleys of the island were becoming maturely opened, seems to be well supported by general principles, for the widening of the valleys of small streams is a slow process compared to the cutting back of shore cliffs by sea waves; but the assumption is further warranted by the special cases of Tahiti and New Caledonia, inasmuch as the high sea cliffs of those islands, the production of which involved a strong recession of the shore line in very resistant rocks, appear to have been developed in the same period of time (while the sea surface stood relatively lower than now) that witnessed the mature widening of the large valleys in the same resistant rocks. Furthermore, volcanic islands outside of the torrid zone, such as Tristan d'Acunha in the South Atlantic, have had their cliffs cut back faster than small valleys are cut down and hence much faster than such valleys are widened, so that their streams cascade into the sea; the same is true on the northeast side of the island of Hawaii. All this seems to show that if the glacial lowering of sea level endured long enough for an island, then undefended by living reefs, to suffer mature dissection by small streams, its shore must at the same time have been cut back in mature cliffs by the waves. Wave attack would be much stronger than valley weathering; hence if drowned valleys are one or two miles wide, the spur ends between them ought to be cut far back in high cliffs: this must be true whether the island rocks are hard or soft. But, as has already been said, sea cliffs are of exceptional occurrence around the shores of barrier-reef islands; the spur ends are as a rule very little cut back, and where low cliffs are seen, they are usually fronted by a visible rock platform, showing that the cliffs were cut at present sea level. Hence as far as these two additional lines of evidence go, it must be concluded, as before, that reef-building corals were generally not killed during the glacial period, and that the flanks of preglacial reefs were protected by growing corals at whatever level the waves beat upon them. Sea waves should not, therefore, be appealed to as of dominating importance in the abrasion of the lagoon floors now enclosed by barrier reefs or by atolls.

It should be noted in this connection that Agassiz reported the frequent occurrence of slightly uplifted "Tertiary limestones" in the atoll rings of the Paumotus: had the corals of those atolls been killed, the uplifted Tertiary limestones should, according to the glacial-control theory, have been cut down to the level of the present lagoon floors, where they would be to-day invisible; but they have not been cut away, and hence, if the uplifted limestones are really Tertiary, the corals there were not killed.

Nevertheless, even if the equatorial ocean were not chilled enough during the glacial period to kill its reef-building corals, the ocean surface must have then been more or less lowered; and, as the outer slope of the reef is steep, the streams of barrier-reef islands must have been temporarily impelled to deepen their valleys. The question thus arises whether normal erosional processes, independent of marine abrasion, could during the glacial period have excavated the valleys that are now invaded by the sea in the existing embayments of barrier-reef islands.

Depth of Valleys in Barrier-reef Islands.—The first step to be taken in attempting to answer the above question is to deduce the essential features of barrier-reef islands, as they existed just before the glacial period, on the assumption that whatever reefs then surrounded them had been formed by outgrowth on still-standing foundations, in accordance with the postulates of the glacial-control theory. These features must as a rule include a less or more dissected volcanic cone, descending to the simple, unembayed shore-line that was formed when the volcano was built up; a surrounding reef-plain of lesser or greater breadth, on which a delta advances opposite each valley mouth; the structure of the reef being that of an advancing talus, lying on a non-eroded, submarine volcanic slope, with coral in place only in the upper 120 feet of its total thickness.

Now around an island thus constituted, the sea is supposed to sink to a lower level, and as a first result the streams are impelled to transect the reef and deepen their valleys in the volcanic cone; then the sea is supposed to rise again and transform the valleys into bays: if several changes of level take place, one in each epoch of the glacial period, the observed embayments will represent the integrated result of all of the changes. The transection of the reef limestones may be a relatively short task, but the incision and still more the widening of valleys in the resistant lavas of volcanic islands or in the crystalline rocks of New Caledonia and Queensland is a task of slower accomplishment. It is moreover questionable whether the greatest possible lowering of the sea surface during the glacial period was sufficient to permit the erosion of valleys to the depth indicated by the form of the spurs that enclose the present embayments of certain islands.

In judging this matter, it must be borne in mind that the valleys of small streams are steep-sided only during the early or immature stages of their whole cycle of erosion, while downward corrasion is still rather active; when downward corrasion practically ceases the slower process of lateral corrasion in the mature stage of the cycle allows the valley sides to weather to gentler slopes. Hence if a maturely open, flat-floored valley be partly submerged, its depth will not be indicated by prolonging its side slopes downward until they meet; but if a steep-sided immature valley be partly submerged, its depth may be fairly estimated in that way. Now the existing embayments of certain barrier-reef islands are enclosed by spurs of relatively steep slopes, which must be interpreted as the sides of relatively immature valleys, not so far advanced in their pre-submergence development as then to have had flat floors; hence their depth near the bay mouths may be fairly determined by the depth at which the downward prolongation of the bay sides intersect; and this is often as much as 600, 800 or perhaps 1000 feet. So great a depth of erosion cannot be reasonably ascribed to the revival of the streams during the glacial period.

Age of Valleys in Barrier-reef Islands.—But although some of these half-drowned valleys are rather steep-sided, even the narrowest of them are by no means young gorges; and on many islands the bay-filled valleys are of maturely open form, with well-graded, soil-covered sides. In such cases, the most important matter to be considered is not the deepening of the valleys, but, as above stated, the pre-submergence widening that they have suffered even in resistant rocks, such as the lavas of the Fijis, and the crystalline schists of New Caledonia and of Queensland; and likewise the pre-submergence reduction of the less resistant but by no means weak rocks in the last two localities to lowlands of small relief, for submerged lowlands there correspond to submerged valleys elsewhere. The question before us is to compare these indications of pre-submergence erosional work in the Pacific with the valleys and lowlands of formerly glaciated regions, in order to estimate whether the observed amount of valley erosion on the Pacific islands could have been accomplished during the glacial period. The comparison is difficult, because of differences in rocks and in climate, as well as because of a considerable measure of uncertainty as to the preglacial form of the valleys of glaciated regions; the result of the comparison will therefore be rather an impression than a demonstration. It is to the effect that the hard-rock valleys and weaker-rock lowlands of such glaciated regions as the northeastern United States, northern Great Britain, central France, and the marginal areas of the Alps are largely of preglacial origin, that they were not greatly changed by normal erosion during the glacial period, and hence that they have required a much longer time than the glacial period to reach their present erosional development; therefore the comparable valleys and lowlands of erosion on Pacific islands could not have been excavated during the glacial period, much less during that part of the glacial period represented by the sum of the glacial epochs.

Hence it is, as above noted, not so much the depth of valley erosion even by slow-working agents such as small streams that is the most important matter to be considered in this comparison, but the widening of hard-rock valleys and the general degradation of weaker-rock lowlands by the much slower processes of weathering, washing and creeping. The incision of rather narrow and occasionally cliff-walled valleys with cascading streams of steep descent, while the baselevel of erosion was formerly relatively lower, in the slopes of a relatively young volcanic island, such as Ovalau in the Fiji group, with the resultant development of short and small embayments when the island was submerged to its present shoreline, as in the middle sketch of fig. 6, represents only a moderate beginning of the erosional work that has been accomplished in more maturely dissected and more intricately embayed islands, like Vanua Levu or Kandavu in the same group, or like Huaheine, Raiatea and Tahaa in the Society group, as in the left-hand sketch; and only a still smaller beginning in the reduction of a massive volcanic cone to skeleton islands, as in the right-hand sketch, like Borabora, taken as a typical example by Darwin and Agassiz, or Gambier island, similarly instanced by Dana. Again let it be remembered that the most significant feature here to be considered is not the depth of erosion below present sea level, as indicated by the breadth of the embayments and the slope of their sides in the less maturely dissected islands, although the depth thus indicated is, as above noted, frequently greater than the estimated depression of the sea surface during the glacial period; but the graded side-slopes of the open valleys that admit broad bays far in toward the center of the more maturely dissected volcanic masses; for in view of the moderate amount of general subaerial degradation accomplished in resistant rocks since the deposition of the earliest glacial deposits, it must be inferred that the excavation of late-mature valleys in volcanic masses demands a longer period of time than the whole of the glacial period.

Fig. 6.

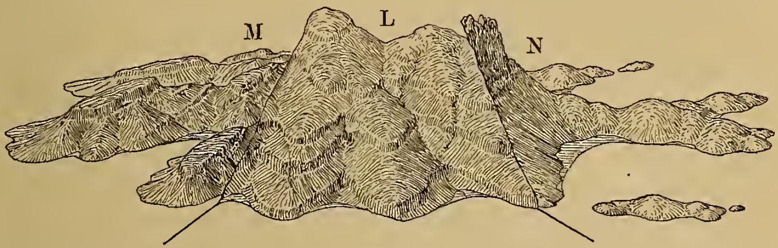

Fig. 6. Types of submature, L, mature, M, and late mature, N, dissection of a volcanic island within a barrier reef.

The detailed form of certain spur-ends is significant in this connection. Basset-edge outcrops, as in M, fig. 6, are of fairly common occurrence near spur ends, because the terminal slope of the spur, although by no means resembling a sea-cliff, is not infrequently steeper than the dip of the volcanic beds that may be traced along the spur sides: excellent examples of such forms are found in Huaheine, Raiatea and Tahaa. From the best determinations that I could make, such spur ends have been slowly fashioned by long enduring subaerial degradation, unaided by the active erosion of streams or by the still more active attack of unimpeded sea waves. The glacial period does not appear to have been long enough for the accomplishment of so large a measure of sculpture by general weathering. Yet spur ends of this kind are often wrapped around by fringing reefs within the lagoon of a barrier-reef, and this indicates that erosion with respect to a lower baselevel than the sea surface of to-day has taken place for a longer time than the glacial period.

The partly submerged coastal lowlands within the Great Barrier reef of Queensland, as interpreted by Andrews, as well as those of New Caledonia, both of which I saw last summer, are eloquent witnesses to the same conclusion, though they offer their testimony so unobtrusively that it has received less attention than the more outspoken testimony of steep-sided embayments. In both these cases, the cycle of erosion that preceded the submergence by which the present coast line was embayed and the up-growth of the present barrier reefs was permitted, lasted long enough in certain districts to open mature valleys in resistant crystalline rocks, and to reduce well indurated stratified rocks to rolling lowlands scores of miles in extent; sometimes to local peneplains several miles in width. It seems inadmissible to ascribe so great an erosional work to a time so short as the sum of the glacial epochs. Hence it must be concluded that the depression of the sea surface during the glacial period was not great enough in amount or long enough in duration to account for the pre-submergence forms of barrier-reef islands.

Several lines of evidence, which have not, I believe, been considered before, thus lead to the rejection of changes of sea level and of sea temperature, or of sea level alone, during the glacial period as sufficient cause for the observable features of the barrier-reefs and their associated islands in the archipelagoes that I visited: hence I must reject the processes of glacial control as sufficient explanation of the atolls of the torrid zone also. Changes of sea level during the glacial period must have taken place in some undetermined measure, and they may possibly have had secondary importance in permitting the transection of formerly continuous reefs by stream-cut notches which, now flooded, appear as "passes" not yet closed by renewed coral growth; or more probably in modifying the rate of submergence and of reef-growth, as is briefly considered in a later section (p. 267); but glacial control does not seem to have been sufficient to produce the primary effects that have been attributed to it. The effects of changes in sea level and sea temperature during the glacial period seem to me to have been subordinate to the larger effects of a more efficient cause.

The Borders of the Coral Zone.—While the evidence given above has led me to reject the glacial-control theory as affording an adequate cause for the features of the great majority of coral reefs, it should be added that the equatorial belt of the Pacific is not the best region in which to test a theory which is based on the assumption that the reduction of ocean surface temperature during the glacial period was sufficient to kill the corals of the Pacific reefs. A better test of the theory might be made on the borders of the coral zone, where the ocean is now only just warm enough to permit the growth of corals, and where the corals would have been first and longest killed by any lowering of temperature during the glacial period. Hence if the processes of the glacial-control theory worked alone, unaffected by any subsidence of the ocean bottom and its volcanic cones, it is on the borders of the coral zone that their effects should be most visible to-day: or if the glacial-control processes worked in conjunction with continuous ocean-bottom subsidence, it is on the borders of the zone that their combined effects should be most manifest. I had no opportunity of visiting any of the northern- or southernmost coral reefs, except for a brief visit to the Hawaiian island of Oahu, and for a rapid passage across the southern limit of the Great Barrier reef of Australia: it seemed quite impossible to account for the facts that I there observed—or for the much larger store of facts recorded on large-scale hydrographic charts—by the glacial-control theory alone.

Certain islands in the South Pacific, especially Norfolk island, east of Australia, rise in bold cliffs from extensive shallow platforms, on which a good number of soundings in depths 20 or 30 fathoms record "c r l" (coral) on the bottom. Certain northwestern members of the Hawaiian group, notably Midway, Lisianski and Nihoa islands, rise from similar platforms. It is possible that these extensive platforms may be to a greater or less degree the result of marine abrasion by the lowered and chilled sea of the glacial period, and that the imperfect development of reefs upon them to-day may be due to rapid submergence that would result, as will be shown in a later section, from the combined action of island subsidence and rising ocean level at the close of the glacial period. But it is the Marquesas group at the eastern limits of the coral seas and to-day without barrier reefs, that, according to the scanty accounts available, should present the effects of the glacial-control theory in their most interesting development; for detailed charts show that the embayments of these islands are separated by truncated spurs, such as are demanded by the glacial-control theory, but such as are prevailingly absent in the warmer seas. A special study of that group with particular reference to the several rival theories of coral reefs would be highly instructive.

The Elevated Reef of Oahu.—Our attention may now be turned to the second group of independent witnesses regarding the origin of sea-level reefs; namely, the reefs of an earlier day now elevated above sea level. It has long been known that the island of Oahu in Hawaii is bordered along part of its shore by an elevated coral reef at an altitude of 20 or 25 feet. The conditions of its origin have been much discussed; the record of "coral" in borings at a depth much greater than that at which corals can grow has been taken to prove that the reef grew upwards as the island sank; but Agassiz has pointed out that the so-called "coral" is only the well-borers' offhand name for any limestone fragments that have been brought to the surface; and that even if they were undoubtedly coral, they might be talus fragments that had rolled down from a surface reef; hence such records, until more fully studied, prove little or nothing.

In the above-mentioned review of various theories, under the title of "The Home Study of Coral Reefs," published after my departure on the Pacific voyage in January, 1914, the following statements were made:—"Special attention should be called to the unlike features presented between recently uplifted reefs that had been previously formed by outgrowth around a still-standing central island, and recently uplifted reefs that had been previously formed by upgrowth around a subsiding central island. Reefs of the first kind should contour around the former shore line, but without entering any valleys that may have been eroded with respect to the then sea level. . . Reefs of the second kind, or their lagoon limestones, should enter every valley, so as to extend inside of a line connecting the outermost outcrops of volcanic rocks in the spur ends at the former shore line" (Bull. Amer. Geogr. Soc., xliv, 1914, 726, 727). The large-scale contour map of Oahu, prepared by the Engineer Troops of the U. S. Army, 1909–1913, a manuscript copy of which I had opportunity of seeing in Honolulu, made it possible to select good localities for testing these deductions; and on my second day on the island I drove with Professor W. A. Bryan, of the College of Hawaii, to Wailupe valley in the younger volcanic mass of eastern Oahu, several miles east of Honolulu, and immediately found the reef limestones with abundant fossil corals several hundred yards inside of the "line of volcanic outposts." A later excursion by rail to the west coast of the island showed similar limestones in the much larger valleys of the older volcanic mass of western Oahu, especially in the great valley of Lualualei; the breadth of this valley in heavy lava beds represents a far greater erosional work than could have been accomplished during the glacial period. There seems to be no possible explanation for these occurrences but the upgrowth of the reefs during a considerable submergence of the island, after it had long been standing higher than now; the submergence being followed by a smaller emergence after the reefs and their lagoon limestones had been formed. If the shore line of the island were drawn for the period of maximum submergence, it would be strongly embayed on the eastern, southern and western coasts, but less so on the northern coast. The embayments must have been longer than the inward reach of the limestones now visible, for the innermost limestone seems to have been covered by detritus washed down from the valley heads.

The elevated reef is broadest along the western part of the southern coast, and here it is entered by the branching "lochs" of Pearl harbor, which are neither more nor less than drowned valleys of the most normal kind: hence the elevated reef has stood for a time higher than now; its first emergence has been followed by a smaller submergence, the difference between the two movements being the twenty or more feet of its present elevation, It is evidently in association with the latest small submergence that the present fringing reef of Oahu has been formed.

Elevated Reefs in the Fiji Group.—Most of the geological visitors to the Fiji islands have mentioned the elevated reefs of Walu bay, a small cove a little north of the capital, Suva, on the largest island, Viti Levu. Some observers, taking account only of these and other high-standing reefs, and neglecting altogether the evidence presented by the embayed coast lines, have concluded that the Fiji group is in a region of elevation, and hence that its reefs cannot have been formed by upgrowth during subsidence. The case is by no means so simple as that; for many of the islands give evidence of alternations between emergence and submergence at different dates and by different amounts.

The two elevated reefs of Walu bay are of small dimensions; they rise about 100 feet above sea level; each reef has a thickness of about ten or fifteen feet, and lies intercalated between beds of "soapstone" or volcanic muds and rare pebble beds, here dipping 7–10° southward and extending over many square miles of surface. The marine origin of the soapstone is proved by various fossils as well as by the intercalated coral reefs; hence they have suffered emergence of at least 100 feet. Their seaward dip is believed to be that of original deposition on the advancing front of a river delta, probably that of the Rewa, the largest river of the island, which is now building an extensive delta at present sea level a few miles to the east. The soapstone beds of the emerged delta were nowhere seen in contact with their foundation; but a few miles east of Suva a creek, that has cut a valley across them, disclosed in its rapids a little distance inland from the soapstone area and a few feet above present sea level, a ledge of volcanic bowlders and cobbles, water-worn and well cemented; it was therefore concluded that when these cobbles were rounded the island was standing at least as high as now; that a submergence of a few hundred feet then permitted the deposit of the delta beds, in which the intercalated reefs mark short-lived periods of local coral growth, prevented earlier and later by excess of muddy sediments, but allowed for a time while the delta-forming river mouthed some distance away; and that emergence placed the delta, with its little local reefs, in an elevated position. Since then, mature valleys have been eroded in the high-standing delta; the valleys are now embayed, and the embayments are more or less filled by sea-level deltas and mangrove swamps, as may be seen at Walu bay, for that little cove and its several neighbors are nothing more than drowned-valley embayments; hence emergence has lately been followed by a smaller submergence; it is presumably in association with this latest submergence that the present barrier reef of Viti Levu has been built up. The broad, now delta-filled valleys of the larger rivers were probably excavated or re-excavated during the last emergence, while the creeks were cutting small valleys; and the broad delta-plains of the large rivers, extensively cultivated in sugar-cane plantations, were formed during and since the last submergence.

It was possible for me to examine only two of the larger elevated reefs in the Fiji group—those of Vanua Mbalavu and of Mango islands—in sufficient detail to discover their structure and to infer their history. Only the elevated reef of Vanua Mbalavu will be here described. Its limestones were usually so weathered or incrusted as to conceal their bedding, but at two points in a bay, block 7, fig. 7, about a quarter of a mile apart, and several hundred feet below the hilltops of the sharply dissected mass, well-defined horizontal stratification was seen, such as must occur in the lagoon deposits of an up-growing reef around a sinking island (see sector M, fig. 9), but such as could not be formed in the slanting talus beds of an out-growing reef around a still-standing island. Of greater dimensions and of greater importance than these details was the unconformable relation between the limestones of the uplifted reefs and their volcanic foundation, as seen in Vanua Mbalavu, and as represented in the foreground section of fig. 7. This relation was not attested by the discovery of actual surfaces of contact between the two structures, which would be difficult to find and to follow under deep-weathered soils covered by dense growth of reeds or trees, but was determined only by the resemblance of the general line of contact, as seen from a little distance away, to the profile of the uncovered slopes of the volcanic mass in other parts of the island. The uncovered slopes have evidently suffered long-continued erosion, for they exhibit mature or subdued spur-and-valley forms of insequent branching arrangement, such as only long-continued erosion can produce in volcanic masses; hence the similar volcanic slopes under the limestones of the uplifted reefs were also believed to have suffered erosion before the deposition of the limestones upon them, and not to represent the boundaries either of intrusive igneous masses—as some observers have supposed—or of unworn submarine volcanic cones. Similar indications of unconformity between the limestones of elevated reefs and their volcanic foundations were noted in three other Fiji islands. Several important consequences follow, particularly in the case of Vanua Mbalavu, where the old reef as well as the volcanic mass has a dissected surface and an embayed shoreline within the lagoon of a well developed barrier reef. The volcanic island, block 3, fig. 7, must have stood at least as high as it does now before the limestones were deposited upon it, in order that its surface should have suffered erosion down as low as present sea level. The island must then, during the formation of the reef-lime-

Fig. 7.

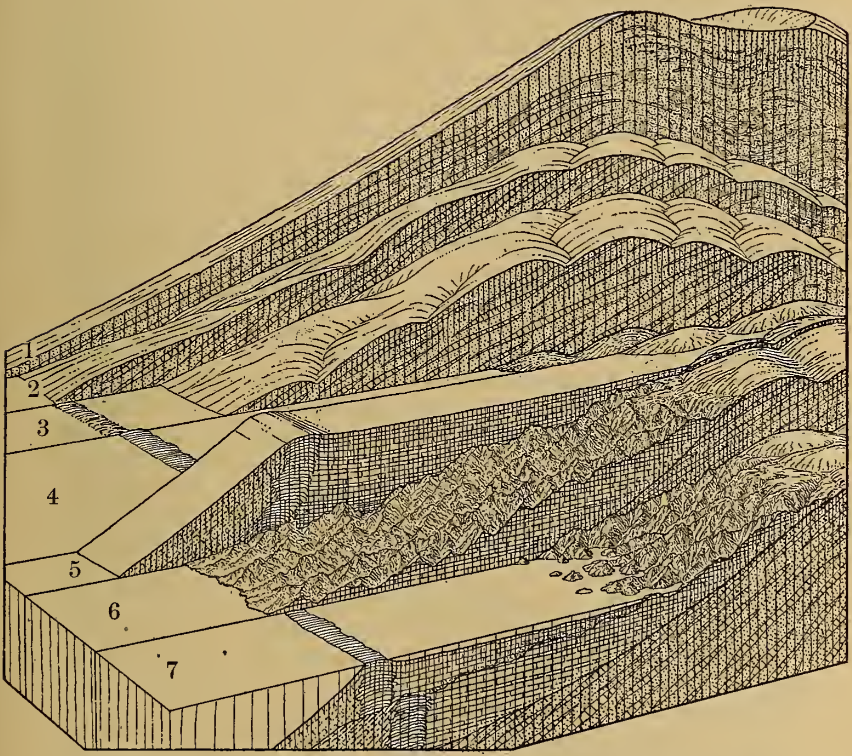

Fig. 7. Successive stages in the development of an uplifted and dissected reef, enclosed by a new barrier reef.

stones, have been submerged to a depth at least as great as the present height of the limestone hills, leaving only the higher volcanic summits visible in the resulting barrier-reef lagoon, as in block 4. Submergence must then have been reversed to emergence, as a result of which the island reached a greater altitude above the sea than to-day, as in block 5; for only a greater altitude could have permitted mature dissection deep enough, as in block 6, to produce after a second submergence the embayed shore line now seen around the dissected limestone mass in block 7, as well as around the volcanic slopes. It must have been during the second submergence that the present barrier reef was formed by upward growth.

It is interesting to recall in this connection that conclusions very similar to those here announced for an elevated reef in Fiji were reached over thirty years ago by W. O. Crosby in his study of the elevated reefs of Cuba. His brief article contains the following points: The lowest reef, "for hundreds of miles, has a sensibly uniform altitude of about thirty feet, and is unbroken, save where rivers have cut through it to reach the sea." It "varies in width from a few rods to a mile or more . . . The indescribably jagged and ragged rock is a limestone, and largely made up of several kinds of modern-looking corals . . . Near the landward side of the reef and especially toward the bottom, as may be observed in the natural sections, the coral limestone is interstratified with layers of sand and gravel, materials washed from the hills while the reef was growing. These beds are generally horizontal or slightly inclined toward the sea. As we should naturally expect, this fragmental material is most abundant near the mouths of rivers, where the reef is sometimes principally composed of it, showing that the modern river valleys are older than the reef."* An unconformable relation between the reef and its foundation is not explicitly stated, but it is clearly implied. In view of all this, Crosby concludes that this reef was formed during a submergence that preceded recent elevation.

The movements of emergence and submergence recognized on Vanua Mbalavu seem to have been local, for similar contemporaneous movements are not recorded on all the Fiji islands; but as the islands are several miles apart, moderate warping without pronounced faulting is sufficient to account for their unlike behavior. Submergence being thus shown to be the apparently essential condition for the formation of the heavy limestone mass of Vanua Mbalavu, now uplifted and dissected, it becomes highly probable that the original stand of the dissected volcanic island was higher, as in block 2, than is shown in block 3, in order that the entire thickness of the older reef

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* On the Elevated Reefs of Cuba, Proc. Boston Soc. Nat. Hist., xxii, 124–130, 1884; see pp. 124, 125.

should have been formed on a submerging foundation. The first submergence and the following emergence may therefore have been of greater measure than the present altitude of the elevated reef. It is important to note, as above stated, that this series of submergences and emergences is not recorded on all the neighboring members of the Fiji group: the island of Mango, only twenty miles away to the southwest, has emerged so recently that its elevated reef is very little dissected; and any submergence that it has since suffered has hardly sufficed to separate its new fringing reef from the present shoreline at the base of the undissected elevated reef; hence, as Agassiz repeatedly insisted, each island must be studied for itself. In view of the local nature of these repeated changes of level, it seems advisable to regard them as due to local movements of the islands concerned, and it would therefore be permissible to speak of them in terms of subsidence and uplift rather than in terms of submergence and emergence, as has here been done, in order not to exclude changes of sea level around a still-standing island; for, as will be shown more fully below, the latter supposition places too much responsibility on the rest of the world in accounting for local phenomena. It should not, however, be forgotten that the prime element in the explanation of the elevated reef of Vanua Mbalavu—namely, its unconformable relation to the volcanic foundation—is not certified by detailed observation of contacts, but only inferred from a general view of the two masses. Further study on the ground is much needed here.

Elevated Fringing Reefs in the New Hebrides.—Mawson's account of the New Hebrides islands* shows that elevated reefs are found on nearly all of them. They are particularly abundant on Efate, where they commonly rest upon horizontally stratified "soapstones," presumably formed of decomposed volcanic ashes and dust, and containing, according to Mawson, various pelagic organisms which indicate deposition below sea level. The reefs are usually in the form of benches or terraces of moderate width, and hence belonged when formed to the class of fringing reefs. They now stand at various altitudes up to 1000 or 2000 feet, and seem to be nearly horizontal: hence it has been concluded for these reefs, as for many others similarly situated, that they were formed during pauses in the emergence to which their present altitude with respect to sea level is due.

This conclusion is by no means imperative for the elevated reefs of Efate, in view of their conspicuously unconformable relation to the soapstones on which they lie. The unconform-

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* D. Mawson, "The Geology of the New Hebrides," Proc. Linn. Soc. N. S. W., 400–485, 1905.

ity is clearly shown in Mawson's section of a critical locality, which I had opportunity of reviewing, thanks to the most considerate attention of various officials. Hence it must be supposed that Efate, after standing low enough to receive an extensive cover of marine strata, emerged high enough (about 1,000 feet) for the cover to be deeply dissected; that it was submerged low enough for reefs to be formed on the higher members of the covering marine strata, and then emerged (about 800 feet?) to its present altitude, leaving some of its valleys drowned as bays. As to the reefs at intermediate levels, it is conceivable that they were formed either during pauses in emergence after a rapid submergence, or during pauses in submergence followed by a rapid emergence, or both. Certain details of reef structure in relation to the soapstone foundation lead me to prefer the second explanation; for of two reefs not differing greatly in altitude, the higher one seemed to lie upon the upper surface of the lower one; if the lower one were built forward from the frontal slope of the higher one, the first explanation would be preferred. It is quite possible that some reefs were formed during pauses in emergence, while others were earlier formed during pauses in submergence; but in either case, the unconformable relation here so strongly displayed demands a double change of level; unless, indeed, the slope of the soapstone hillside is a fault-scarp that was formed beneath sea level and fringed with reefs during pauses in its first and only emergence: but the general form of the hillside that I ascended and its relations to its neighbors seemed to me to exclude such a possibility. If further observation should discover that the marine soapstone strata lie unconformably on a dissected volcanic foundation, it would then be necessary to conclude that submergence had taken place before the soapstones were deposited, and thus two double movements would be proved.

In any event the separation of the Efate reefs in distinct terraces shows that coral growth could not keep pace with the movement—whether emergence or submergence—by which their separation was caused. A similar conclusion is suggested by the narrow-lagoon barrier reef, hardly more than a wide fringing reef, on the strongly embayed island of Espiritu Santo, farther northwest in the same group; for the embayments of that island indicate a liberal measure of submergence, which should have produced a wide-lagoon barrier reef, if the reef had grown upward continuously while submergence was in progress; but as the actual reef has only a narrow lagoon, upward growth was probably discontinuous; the earlier-formed fringing reefs having been drowned by successive movements of rapid submergence, and the present sea-level reef having been begun anew, after most of the total submergence was accomplished.

The Elevated Loyalty Atolls.—The three Loyalty islands, between New Caledonia and the New Hebrides, are elevated atolls. The two southeastern members, Lifu and Maré, are plateau-like masses, about 50 and 40 kil. in diameter; their margins are a little higher than their broad central plain, which is in both islands remarkably level over large areas at an altitude of about 40 meters in Lifu and 70 in Maré. Their external slopes are very little dissected; hence their emergence must be of recent date. A French observer, Balanza, has reported that fossil corals are abundant in the higher margin of Lifu, but that the limestone of the central plain shows no stratification and contains only fossil shells. This is inconsistent with the theory of an outgrowing reef on a still-standing foundation, back of which the lagoon is excavated by solution; for the lagoon floor of such a reef should show a slanting stratification and contain abundant fragments of coral; but it is consistent with the theory of an upgrowing reef on a subsiding foundation, for the lagoon deposits of such a reef are largely free from corals. Maré is of special interest from possessing in its center a low knob of dense volcanic rock, a few hundred meters in diameter, some ten meters in relief, with gentle lateral slopes; hence not so high as the plateau margin. The limestone close around the knob shows no signs of alteration or disturbance by intrusion. This is interpreted to mean that the knob is the top of a subsiding volcanic island, from which the loose-textured, scoriaceous surface parts had been denuded so far as to give the highest summit a well-subdued form before submergence allowed the deposition of the lagoon limestone around it. The knob cannot owe its reduction in size to wave attack on a still-standing island; for, in that case, it should still be bordered by cliffs, while as a matter of fact its slopes are very gentle; absence of dissection on the outer slopes of the island shows that emergence is of too late a date for any sea cliffs, a little earlier cut by the waves in hard volcanic rocks, to have disappeared since then by weathering. Nor can the knob owe its reduction in size to the general degradation of a still-standing island, for in that case much volcanic detritus should be found over the limestone plateau, yet no trace of such detritus is to be seen. A boring in the limestone a kilometer distant from the knob might be expected to reach volcanic rock at a depth of some 200 meters; the mixture of volcanic detritus with limestone in increasing proportion as the volcanic rock is approached, would be decisive in favor of submergence during the upgrowth of the reef. If the buried slopes of the denuded volcano are similar to those of various volcanic islands in the Fiji group, the thickness of the limestone at the margin of Maré must be at least 5000 or 6000 feet.

Uvea, the northwestern member of the group, is a gently tilted atoll about 40 kil. in diameter; its eastern half is uplifted in an irregularly crescentic ridge, highest and broadest at the middle, lowest and narrowest at the horns; the depressed western half is marked by a series of small islands that presumably grew up to the sea surface as down-tilting took place. The lagoon deepens very gradually from east to west; its eastern border is marked by a long beach composed very largely of delicate shells and their fragments, without corals.

Testimony of Elevated Reefs.—The glacial-control theory seems to have little or no application in explaining the elevated reefs above described; some of them must have been formed and placed out of reach by emergence before its processes came into operation. Let it be remembered, however, that the glacial-control theory does not attempt to explain coral reefs in the larger sense of the term, which includes not merely the visible reefs at the sea surface, but the whole submarine limestone mass under the lagoon as well as under the reef; the glacial-control theory accepts the reef-masses as completed in preglacial time—presumably on still-standing foundations—and merely gives a special explanation of their lagoons and of so much of the reef-mass as now encloses the lagoons.

As to other theories of coral reefs, it is certainly significant that the only one of them which receives any support from the facts here stated regarding elevated reefs is Darwin's theory of upgrowth during subsidence. This is the more important when it is remembered that the above-named elevated reefs were not visited because they were supposed to present evidence in favor of one theory or another, but simply because they were accessible in the course of my voyage. All of them—except the little reefs of Walu bay, near Suva, Fiji, which are intercalated in a series of inclined delta-front strata, and the great elevated atoll of Lifu in which no foundation is visible—rest unconformably upon eroded foundations, which must have subsided before the reefs were formed upon them. The entrance of the Oahu reef-limestones into the valleys of that well-dissected island, the horizontal attitude of the strata deep in the mass of the reef-limestones of Vanua Mbalavu, and the freedom of the central limestones of Lifu from fossil corals, all testify against the theory of out-growing reefs on still-standing foundations. The large thickness of the limestones of Vanua Mbalavu, Mango, and the Loyalties testifies against the theory of veneering reefs on wave-cut platforms. Hence although the testimony here presented by elevated reefs is more varied and more complicated than that offered by the embayed shorelines of the central islands within sea-level barrier reefs, it is no less consistently in favor of upgrowth during submergence. But by very reason of the variety and complication of the evidence furnished by elevated reefs, the need of studying each example for itself is the greater.

Submergence and Subsidence.—In view of the foregoing discussion it appears reasonable to conclude that a submergence of the foundations of barrier reefs during the formation of the reefs is demonstrated, and that a similar submergence of foundations took place during the formation of various other reefs now elevated ; thus the long-lasting issue between the several still-stand theories of coral reefs and certain other theories which postulate submergence may be regarded as settled in favor of the latter, as far as reefs that have provided independent testimony about their origin are concerned. As to atolls, which afford no such testimony, and as to barrier reefs and elevated reefs which have not been examined, it is still logically permissible to maintain a belief in their formation by some still-stand process, if any one wishes to do so.

Among the theories which postulate submergence as the cause of upgrowth for existing sea-level reefs, the glacial-control theory, acting alone, appears to be insufficient ; and it does not seem to have been in operation at the time of the formation of certain elevated reefs. Hence some other cause of submergence, strong in value and long in intermittent operation, must be sought for.

It might seem, at first thought, that no other cause than subsidence, as postulated in Darwin's theory, could be suggested ; yet it must soon become evident that the embayed shoreline of a barrier-reef island, together with the upgrowth of the surrounding barrier reefs, may be quite as well explained by a rise of the sea surface around still-standing islands as by a sinking of the islands beneath a still-standing sea surface ; and likewise that all the indications of submergence given by the structure of uplifted reefs can be explained as well by a contemporaneous rise of sea level as by a subsidence of their foundations. It is in order to avoid begging the question thus opened that the word, submergence, has been used on the foregoing pages instead of subsidence. Truly, if signs of recent submergence were found around all the coasts of the world, and if the measure and date of the submergence were everywhere the same, so uniform and universal a change would have to be explained by a rise of sea surface ; but signs of submergence are by no means universal. If indications of recent and uniform submergence were found on a majority of coasts, insular and continental, so extended a change of sea level might also be best explained by a rise of the sea surface, accompanied by a rise of those coasts which do not show submergence and a still greater rise of those that show emergence ; but although many coasts certainly do show signs of recent submergence, many others do not ; and even where recent submergence has taken place, its measure and date are not known to be so closely alike as to demand a rise of sea level for its explanation. Indeed, the explanation of the submergence that is associated with the development of barrier reefs by a general rise of sea level recalls Suess's explanation of the recent emergence of certain high-standing coral reefs by a general fall of sea level. Evidently, if all the high-standing coral reefs were of the same height, as Suess some thirty years ago thought they were, and if they were all similarly undissected—a matter to which Suess gave no attention—and if correspondingly recent and undissected shorelines were found at the same altitude around most of the coasts of the world, as Suess seems to have thought was the case, and if all barrier-reef islands showed recent elevation instead of possessing embayed shorelines—a matter which seems to have been overlooked in Suess's argument—the accordant emergence of all these features would be best explained by a fall of sea level : but high-standing coral islands are now known to have very unlike altitudes and to be very unequally dissected, while various continental and insular coasts indicate emergence and submergence of the most diverse amounts and dates ; hence the phenomena of emergence which Suess thought were simple and uniform and widespread enough to be explained by a single fall of sea level, are now found to be complex and diverse to such a degree that they can be explained only by correspondingly complex and diverse crustal movements, in addition to any universal change of sea level that may have recently taken place. I cannot help feeling that any appearance of a uniform measure of submergence in various barrier reefs and atolls will, when closely studied, be found to include a significant measure of diversity; and that whatever share of such submergence may be attributed to a universal rise of sea level, many local departures from uniform submergence will remain to be explained by local crustal movements.

The fuller discussion of this aspect of the coral-reef problem would require, first, a consideration of the large measures of submergence at different dates that are involved in the formation of various coral reefs, some at sea level, some elevated ; and second, a consideration of the terrestrial processes that are involved in producing large measures of submergence at different dates. As to the first consideration, let it suffice here to point out that certain reefs of the Fiji group alone demand an earlier submergence and others a later submergence, each of about 1000 feet; thus the total submergence to be accounted for becomes formidable.

Possible Causes of Submergence.—As for the second consideration, a rise of sea level resulting from an increase in the volume and depth of the ocean through the addition of water that escapes from deep within the earth by volcanic eruptions and otherwise seems entirely inadequate to cause the submergence demanded by coral reefs; all the more inadequate when it is remembered that some decrease of ocean volume and depth might be caused at the same time by the retention of rainwater in the continental masses by the hydration of previously nonhydrous minerals.

A more available cause for a rise of sea level can be imagined in an upheaval of part of the ocean bottom, as in the upper section of fig. 8, and the possibility of such upheaval is clearly indicated by the occurrence of elevated coral reefs on various islands. But there are certain general considerations which make it extremely improbable that the submergences, in association with which coral reefs have been formed, are to be thus explained in any large measure. In the first place this cause of submergence is, like the preceding, a wasteful one, for it raises the ocean surface everywhere; it is indeed an extravagantly wasteful cause, for the measure of ocean-bottom uplift must be greater than the necessary submergence in the ratio that the area of ocean-bottom uplift is smaller than the entire ocean-bottom; if the area of uplift is one-twentieth of the ocean area, the uplift must be 6000 feet in order to raise the ocean surface 300 feet. Evidently one who regards Darwin's theory of subsidence as demanding excessive deformation of the ocean floor cannot find satisfaction in this alternative theory. In the second place, this cause is, like the preceding, an involved one, for it requires a uniform and contemporaneous submergence of all the shorelines of the world, except where local counterbalancing deformation occurs. In the third place, the uplift of a certain area of the earth's crust without any compensating subsidence of an adjacent part demands the improbable assumption that the uplift is due to increase of volume only in that part of the earth's mass which lies beneath the uplifted area; it is more reasonable to suppose that the rise of the uplifted area involves a roughly compensating subsidence of some other area, the two movements being connected by a lateral transfer of material at some unknown depth within the earth. In the case here considered, the least extravagant arrangement of the compensating movements would be to have the area of uplift entirely beneath the ocean, and the area of subsidence entirely within a continent, as in the upper section of fig. 8; for then the subsidence would not, by tending to lower the ocean surface, lessen the effect of the uplift in raising it: but so specialized an arrangement of uplift and subsidence is extremely improbable for an earth on which only a quarter of the surface stands above the ocean, and on which much of that quarter stands at a small altitude above sea level. If, as is more probable, both areas were in part or entirely beneath the ocean, as in the second section of fig. 8, the change of ocean level would not be proportionate to either movement, but only to the failure of their compensation. If the two areas were entirely beneath the ocean, and each movement included, for example, one-twentieth of the whole ocean area, then a rise of 300 feet in the ocean surface would demand enormous movements of uplift and subsidence, such as 20,000 and 14,000 feet, in order that the failure of their compensation should be 6000 feet. Yet the thickness of certain reefs must be much greater than 300 feet. On the east side of the island of Wakaya, a tilted fault-block in the center of the Fiji group, the reef is probably 1000 feet thick; the uplifted reefs of the Loyalty islands show 300 feet of limestone, and their total thickness may well be several thousand feet; certain elevated reefs in Fiji expose 800 feet or more of limestone without showing their foundation. Enormous measures of uplift else-

Fig. 8.

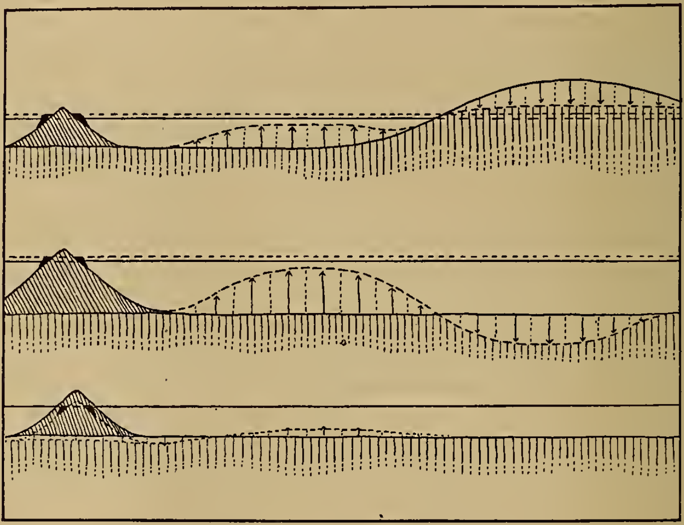

Fig. 8. Submergence caused by rise of ocean surface (upper and middle figures) and by subsidence (lower figure).

where would be required to raise the ocean surface by such amounts.

A happy escape from the embarrassment of these super-extravagant measures may be found by assuming that the area of compensating subsidence includes the district of the reefs themselves, as in the third section of fig. 8; for then the subsidence need be no greater than the measure of submergence, except for any small rise of sea level that may result from an excess in a neighboring, compensating uplift, or from unrelated uplifts, and except for a very slight fall of sea level due to the withdrawal of a small volume of water from all the rest of the ocean in order to cover the submerged part of the subsiding islands. But behold, in this escape from the embarrassments inherent in the proposed alternative for Darwin's theory of subsidence, we are led back to that very theory; hence it may now be more directly considered.

Fig. 9.

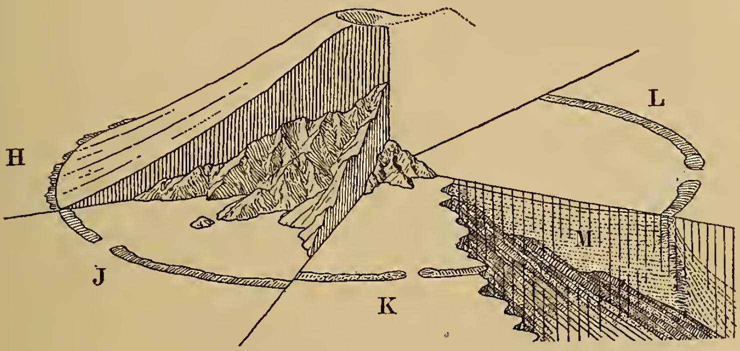

Fig. 9. Deduced stages of an upgrowing reef on a subsiding island.

Darwin's Theory of Subsidence.—In Darwin's first book on Coral Reefs (1842) he explicitly recognized the idea of compensating uplifts and depressions, for in describing areas of unlike movement in the Pacific he said they were related "as if the sinking of one area balanced the rising of another" (p. 145). Thus the condition postulated in the preceding paragraph should be regarded as a characteristic element in his treatment of the coral reef problem, although it is not one that he greatly emphasized. It is here further considered, its deduced consequences being illustrated in fig. 9; especial attention should be given to the section, M, of the atoll sector, L.

If a barrier-reef group like the Society islands sinks with a subsiding ocean bottom, and a neighboring part of the ocean bottom suffers a compensating uplift, the general sea level may neither rise nor fall, except for the small changes mentioned above. Thus the submergence of the island shores may be about equal to the local subsidence of the ocean bottom, as Darwin supposed. If the area of compensating uplift is in part or in whole continental, the submergence will be somewhat less than the subsidence; for example, if the subsiding area is one-tenth of the ocean bottom, and the amount of subsidence is 500 feet, while the compensating uplift is entirely within a continent, the amount of submergence will be 450 feet. Hence, in so far as an economical method is a probable method, Darwin's theory of regional subsidence of the ocean bottom is a more probable cause of the submergence indicated by barrier-reef islands than the alternative theory of a rise of sea level as a result of an uplift of the ocean bottom elsewhere; but such probability is only a first step toward proof. In my own opinion final proof can not be reached in a problem of the kind here discussed until we make undreamed of additions to our present knowledge of the earth ; the most that can now be done is, as above, to reach a fair degree of probability. A second step in that direction may be made by considering the diversity in the measure and the date of the submergences which various reef-encircled islands have suffered in different island groups and even within the same group.

In considering this aspect of the problem we will return for a moment to the supposition that the submergences indicated by the embayments of barrier-reef islands and by the unconformable contact of elevated reefs with their eroded foundations are due to elevations of the ocean surface caused by uplifts of the ocean bottom elsewhere; and we will recall that when a reef-island is thus submerged, all other islands and all the continental coasts of the whole world must, as already stated, suffer submergence of the same date, amount and rate, except in so far as local movements cause departures from this improbable uniformity. Local differences in amount and rate of submergence in the coral-reef region may be produced if it shares in varying measure the ocean-bottom uplift that causes the rise of the ocean surface, or the compensating subsidence that lessens the rise; but differences in the geological date of submergence can be caused only by different submergences; and here the theory of a rising ocean surface encounters a serious difficulty. All the islands and all the continental coasts that did not take part in an earlier submergence, during which a now elevated coral reef was formed, must at that time have been uplifted by the amount of the submergence; later on, all the islands and all the continental coasts that do not take part in the submergence in association with which a new sea-level reef is now forming, must then a second time be uplifted by its amount; and so on. It is far beyond the present capacity of geological investigation to determine whether such widespread uplifts have or have not taken place contemporaneously with the formation of the earlier and later reefs; hence this theory is at present not only embarrassing but unverifiable.

On the other hand, if local submergence is due to local ocean-bottom subsidence, more or less closely compensated by neighboring ocean-bottom uplift, then each island or group of islands is submerged when it subsides and by about the amount of its subsidence. Submergences of different dates do not, under this supposition, involve any complicated difficulties, and the explanation of submergence is greatly simplified. Darwin's theory thus explains the reefs and the embayed shorelines of a group of barrier-reef islands by a simple crustal deformation that need not extend far beyond the area occupied by the island group. This simple theory does not hold extravagant movements in extensive regions elsewhere responsible for changes of moderate amount observed in coral-reef areas; and it does not submerge or disturb all the other coasts of the world, continental as well as insular, every time that a group of coral reefs is formed. Darwin's theory, therefore, has the recommendation of being a simple cause for a simple effect. But recommendation is not demonstration, any more than probability is proof. Nevertheless, I believe that the above considerations suffice to advance Darwin's theory of subsidence to so high a degree of probability that it outranks all other coral-reef theories. If general changes of ocean level sometimes take place, dependent either on changes of climate or on movements of the ocean floor outside of the coral zone, the submergences or emergences thus produced appear to be subordinate to those produced by subsidences or uplifts of the ocean bottom in coral-reef regions themselves.

The Problem of Atolls.—The conversion of barrier reefs into atolls by a continuation of the process that converts fringing reefs into barrier reefs is a highly probable matter; for, as already pointed out, it would be unreasonable to suppose that this process, whatever it is, should always have stopped before the central islands of barrier reefs were wholly submerged, and should never have worked in neighboring areas where reefs of identical form but without a central island are given another name. And now that the converting process has, with so high a degree of probability, been shown to be long-continued subsidence of the ocean bottom in the region concerned, and not a change of ocean level during the glacial period or an uplift of the ocean bottom in some other region, it appears reasonable to explain atolls in the same way as barrier reefs.

This conclusion becomes all the more reasonable when the intimate association of barrier reefs and atolls in the Fiji, New Hebrides, and Society groups and elsewhere is noted. The conclusion may seem unreasonable to some students of the problem in the case of large groups of atolls which include no barrier reefs; but, as far as I have been able to discover the ground of that seeming unreasonableness, it rests chiefly on a hypothetical objection to the occurrence of subsidence in oceanic areas—an objection which I believe to be based more on our ignorance than on our knowledge of the earth's structure and behavior. The objection is greatly weakened when it is seen that the submergence of barrier-reef groups by regional subsidence is highly probable, and when it is recognized that if their submergence is due to a rise of ocean level, the uplift of the ocean bottom thus demanded in some other region is much greater than the sinking of the ocean bottom in the coral-reef region demanded by the theory of subsidence.

It is instructive to note that two different schools of geology to-day teach, explicitly or implicitly, directly opposite theories on this recondite problem. One school insists that highlands, such as those of eastern Australia or of northern Arizona, owe their relief, not to radial uplift of their own areas, but to the radial subsidence of the neighboring areas; yet, inasmuch as both these highlands include peneplains of normal erosion, they must once have been lowlands continuous by gentle grades with neighboring low areas and with the sea-surface; and if the neighboring low areas have since then subsided without being submerged, then all the oceans and all the ocean bottoms —and all the continental areas that did not then gain an increased altitude above sea level by retaining their former distance from the earth's center—must have sunk at the same time and by essentially the same amount; thus an implicit consequence of this theory—the theory of still-standing highlands, as it may be called—is that the radial sinking of the ocean bottom must be the sum of all the continental subsidences of different dates, whereby peneplains have been given the appearance of uplifted plateaus. Another school teaches that the ocean bottoms are relatively fixed, or at least very slow to decrease their distance from the earth's center, and explains local high-standing peneplains by local uplift, without notable disturbance of the rest of the world; this might be called the theory of local responsibility.

The theory of still-standing highlands evidently demands a rate and an amount of terrestrial shrinking far in excess of that usually ascribed to the earth; and if it be true, the earth can hardly yet have reached the advanced stage of evolution usually attributed to it, when, as Leibnitz long ago said, "consistentior emergeret status rerum." The theory of locally uplifted highlands is, on the other hand, more accordant with generally accepted views regarding the well-established stability of the terrestrial mass. Hence of the two theories the latter seems much the better grounded; yet not so rigidly grounded as to exclude the possibility of regional ocean-bottom subsidence in the conversion of fringing reefs into barrier reefs or of barrier reefs into atolls, for this is only another case of local responsibility. However this may be, the important thing to note here is that choice between the two theories must be made, not by observation of the visible highlands of the earth's surface, for all the features of the highlands are as well explained by one theory as by the other; choice must be made by the discussion of inferences regarding the possible behavior of the earth's invisible interior; and in this respect the discussion of the theories of these two opposed schools of geology resembles the discussion of the theories of coral reefs.

Nevertheless, possibility of ocean-bottom subsidence is not a necessity. In the case of atoll groups in which no barrier-reef islands are found, it is easily conceivable that the reefs may have been formed in other ways than by upgrowth from a sinking foundation; indeed, even if nine out of every ten atolls were proved by means of abundant, large-core borings, to have been built upwards during the subsidence of their foundations, some other origin for the unbored atolls might still be conceivable to the agile-minded inquirer; but conceivability is not necessarily credibility. Hence the problem of atolls cannot be regarded as absolutely solved: nor can it ever be absolutely solved until we make vast additions to our present knowledge. Indeed, however far observation of any coral reef is carried, it cannot go beyond the facts of existing structures; while the origin of reefs, whether barriers or atolls, involves unobservable processes of the invisible past as well as unobservable conditions of the unattainable interior of the earth; and the absolute determination of these unobservable elements of the problem is far beyond our reach. The origin of coral reefs must therefore, like the displacement of faulted structures, the uplift of high-standing peneplains, and the metamorphism of sedimentary strata, always remain a matter of inference, however far the observational study of existing reefs is carried. The most that can be done will be to make our inferences reasonably safe; but if in the meantime a highly probable solution for the general problem of coral reefs, including atolls as well as barrier reefs, is wanted—that is, a solution of the kind that is accepted as a "conclusion" in many other geological problems—such a solution is, in my opinion, provided by Darwin's broad theory of upgrowing reefs on foundations that subside with the subsiding ocean bottom, the submergence thus produced being modified only in a minor degree by changes of sea level due to causes outside of the coral-reef region.

The Merits of Darwin's Theory.—The chief merits of Darwin's theory of subsidence are its simplicity, its breadth, its capacity to explain critical facts—the drowned valleys of barrier-reef islands, as in sectors J, K, fig. 9, and the unconformable contacts of elevated reefs on eroded foundations, as in section M—that were not known when it was invented; also the ease with which it may be modified by the addition of supplementary processes without invalidating its own essential process. It contains no postulate so arbitrary as that of a still-standing reef foundation on a fixed ocean bottom, of which the rigidity is relaxed only to permit elevation but not subsidence; it avoids the assumption of great uplifts in other parts of the ocean to produce less great submergence in coral-reef regions, and explains local submergence by local subsidence of the same amount; but it easily accepts the possibility of some submergence or emergence being caused at any time by a general change of ocean level from whatever cause; it understands that other organisms than corals contribute to the formation of coral reefs; it freely recognizes that subsidence may be interrupted by still-standing pauses or reversed by elevation; it considers and accepts the possibility of the outward growth of reefs during still-stands, but regards such outward growth as subordinate to upward growth, because existing sea-level reefs are generally of moderate breadth and because the deltas which occupy the bay-heads of central islands within barrier reefs are generally too small to project into the lagoon; it considers and rejects the explanation of barrier reefs as veneers on abraded rock platforms, because the central islands are not cliffed as they should be if this theory were correct; it perceives the possibility of reefs being established on submarine banks, built up to the shallowness required for coral growth by other kinds of organic deposits, but it accepts this idea, to which Murray later gave wide application, only for rapidly-growing banks near continental borders and rejects it for pelagic banks, where the very slow up-building would be easily overcome by a less slow submergence or outstripped by a less slow upheaval, and where wave-action might sweep away fine deposits in greater depths than twenty fathoms.

Dana's Confirmation of Darwin's Theory.—The chief deficiencies in Darwin's statement of his theory are: the failure to deduce the embayment of central islands within barrier reefs and the unconformable contact of the reef mass with its volcanic foundation as essential consequences of subsidence, and the omission of the possibility of submergence, due to a rising ocean surface, as an alternative to submergence due to a subsiding ocean bottom. The theory as first stated involved a greater uniformity of subsidence over certain large areas than now seems necessary, in view of later discovered facts; but, as noted above, the ease with which the first outline of the theory may be modified so as to account for the new facts is to its advantage, not to its discredit; and after all the new facts are considered, subsidence of the ocean bottom in areas where barrier reefs and atolls prevail is to-day, as it was in Darwin's time, the best explanation that has been offered for the observed phenomena

As to the first deficiency above-named, it seems that after Darwin had invented his theory of subsidence, he came to know that the central islands of barrier reefs were often embayed, but he did not see that the embayments must necessarily result from the partial subsidence of a previously dissected volcanic island, probably because he ascribed many large valleys to marine erosion. It was Dana who, as has already been pointed out, first showed that subsidence must produce embayments; and Darwin's theory thus extended is now regarded by an increasing number of students as more competent to explain coral reefs in general than any other theory yet proposed; but like Darwin, Dana did not clearly distinguish between subsiding islands and a rising ocean surface. However, in view of the considerations presented above under the heading, "Submergence and Subsidence," repeated elevations of ocean level by the amount demanded by many coral reefs appears improbable to the point of inadmissibility; thus the competence of Darwin's theory becomes all the greater. Dana's name should, therefore, be linked with Darwin's in the discussion of coral reefs, not only because he observed various reefs that Darwin did not visit, not chiefly because he was thus led to support Darwin's views, but far more because he brought to light a necessary but unexpected consequence, deducible from Darwin's theory, that Darwin himself always overlooked: for this deduced consequence—the embayment of barrier-reef islands—is confirmed by observation, and, taken with the structural features of elevated reefs, supplies the most compelling evidence of the whole problem.

Subsidence Modified by Glacial Changes of Sea level.—A suggestion made in an earlier section regarding Reefs and Reef Platforms deserves expansion. It has been recognized that changes of sea level and of sea temperature must have taken place in some undetermined measure during the glacial period; but it has been shown that a change of level caused by regional subsidence seems on the whole to have been the dominating factor in the formation of the heavy limestone masses of barrier reefs and probably also of atolls. Let the attempt now be made to discover the results that will follow from the combined action of these two changes; the temporary and exceptional changes due to the glacial period, uniform through all the torrid seas, being superposed on the long-lasting changes due to regional subsidence, which presumably varied in rate and in amount from place to place. The effect of this combination will be to retard submergence while the continental ice sheets are forming, and to accelerate it while they are melting away. During the time of retarded submergence, reefs would tend to broaden by outward growth, and lagoons would tend to be shallowed and filled by outwash from the land, by local organic deposits, and by inwash from the reefs. Atolls might thus be transformed into cays, and barrier-reefs into sea-level flats. Then during the following time of accelerated submergence, the reefs, especially while their corals are still feeble because of a slow warming of the cooled ocean of a glacial epoch, might not be built upwards in all their length as fast as submergence is then taking place; thus a platform, incompletely bordered by a reef, which need not necessarily rise from the platform edge, would result; eventually a complete reef might be established again, but that eventuality may not yet be reached in all cases. Before these possibilities can be regarded as probabilities, much study must be given to them. The most doubtful element in the case is the rate of subsidence and its relation to the rate of change of sea level by glacial control.

If instead of subsiding islands on a sinking ocean floor, we consider stationary islands in an ocean that rises because of an uplift in its floor elsewhere, the same results will follow from combining therewith the changes of ocean level caused by glaciation: or similar results may follow from various combinations of all three processes:—local subsidence, changes of ocean level due to climatic changes, and changes of ocean level due to movements of the ocean bottom in other than coral-reef regions.

It thus appears that oscillations of sea level during the glacial period may work most harmoniously with Darwin's theory of subsidence, and produce significant though subordinate modifications in its consequences; hence to suppose that glacially controlled oscillations of sea level have acted alone during the formation of existing coral reefs seems to me improbable as well as inadequate. It is true that in Daly's exposition of the glacial theory, he announces that it "in no sense excludes complications due to local warpings of the earth's crust," but he adds that changes of this kind are neglected in his argument because of the high probability that they have not "been important enough, since the Tertiary, to affect, by more than a fathom or two, the changes of level assumed" (307). The reasons for this conclusion are not stated, but they are perhaps associated with theoretical views as to the stability of the ocean bottom, which permit the inference that the older oceanic volcanoes must have suffered subaerial denudation long enough for them to approach or reach peneplanation (309)—that is, that they stood still long enough to be worn down almost to sea level.

If the question of insular stability is approached rather from the observational than from the theoretical side, and if the interval of time under consideration is expressed not in terms of standard geological chronology, such as "since the Tertiary," but in terms of the period needed to erode the embayed valleys of barrier-reef islands—this period being, according to Daly's exposition of the glacial-control theory, less than post-Tertiary time, inasmuch as the embayed valleys were, under the glacial-control hypothesis, eroded only during epochs of glaciation—a very different conclusion is reached. In the Fiji group there are several elevated reefs, 600 or 800 feet above sea level, as yet very little dissected; hence they must have been exposed to subaerial erosion for a much shorter period than that required to erode the embayed valleys in volcanic rocks. Two of the Loyalty islands are former atolls, now elevated about 300 feet, but their dissection is hardly begun. On Efate in the New Hebrides, weak "soapstones" overlaid by fringing reefs at various altitudes up to 800 feet show no change since emergence except narrow valleys cut by streams of rapid fall. In view of these large measures of uplift—50, 100 or 130 fathoms—in very recent time, it seems unreasonable to allow subsidence no more than "a fathom or two" in a longer period. Hence if the ocean surface were lowered by a score of fathoms or more during the last glacial epoch, it does not seem altogether unreasonable to suppose that certain parts of the ocean bottom, with the islands standing on it, should have risen or sunk by some such amount in the same time. The combination of subsidence with changes in the level of the ocean surface therefore seems legitimate.

Summary of Results.—The general result of my voyage already announced above, as well as several special results, may now be concisely stated:—

The origin of coral reefs cannot be determined by a study of the visible features of sea-level reefs, for they can be explained by any one of the eight or nine theories that have been proposed to account for them, provided that the postulated conditions and processes of the theories are accepted. Apart from research by deep borings, the true theory can be detected only by the study of associated problems, such as the form of the central islands within barrier reefs, or the structure of uplifted reefs.

The origin of coral reefs, like many other geological problems, involves the discussion of invisible structures and processes to a far greater degree than the observation of visible structures and processes, although the latter must always remain the essential prerequisite of the former. It is for this reason that so much attention is given in the present article to inferences regarding unseen things.

Darwin's original theory of subsidence, supported by Dana's principle of shore-line development, gives by far the most satisfactory explanation of all the barrier reefs that I have visited in the Pacific or studied on large-scale charts; and as atolls often occur in association with barrier reefs, Darwin's theory of subsidence appears to give the best explanation of such atolls also. Atolls that are not associated with barrier reefs may be of some other origin, but this seems very improbable.

Changes of ocean level, resulting from movements of the ocean bottom and causing emergence or submergence of still-standing coasts, are undeniable; but they seem subordinate to the effects of local uplift and subsidence. Hence in the following paragraphs the term submergence will be replaced by its apparent cause, subsidence.

The elevated reef along the south coast of Oahu, Hawaii, was formed during or after a sub-recent period of subsidence, for its limestones enter well-defined valleys of erosion. The sea-level reef of Oahu was formed during a later and smaller subsidence, by which valleys eroded in the uplifted reef were partly drowned.

The Fiji group has suffered various movements of subsidence and elevation by which its many islands were affected in unlike ways. Elevation has occurred in different islands at different times, for some of the elevated reefs are elaborately dissected, and others are very little dissected; still others remain at sea level. The embayments on the larger islands, Viti Levu and Vanua Levu, are largely filled with delta plains. All the reefs, those now elevated as well as those at sea level, appear to have been formed during periods of subsidence, the evidence afforded by the elevated reef of Vanua Mbalavu being especially significant on this point. The medium-sized island of Taviuni has few visible reefs, because its flanks and shores are flooded by sheets of recent lava. The small island of Wakaya seems to be a tilted block of lava beds, not a dissected volcano.

The extensive barrier reef of New Caledonia has grown up during a recent subsidence by which that long and maturely dissected island has been much reduced in size and elaborately embayed; but unlike most encircled islands this one was strongly cliffed around its southeastern end and along much of its northeastern side, before the recent subsidence took place.

The two southeastern members, Maré and Lifu, of the Loyalty group are former atolls, evenly uplifted about 300 feet.

Maré shows a small mass of volcanic rock, once an island in the center of its lagoon, now a low hill rising over the elevated lagoon plain; but the rim which represents the atoll reef around the plain rises higher than the hill-top; hence the volcanic island was completely submerged before elevation took place. Uvea, the northwestern of the three Loyalty islands, is a slightly tilted atoll; its eastern side shows an uplifted reef in crescentic form, 100 or more feet high at the middle of its crescent, and slowly descending to sea level at its horns; a bight on the convex eastern side may result from a land slide into the sea; the tilted lagoon floor slowly deepens westward and is enclosed by disconnected, up-built reef-islands.

The New Hebrides show signs of recent uplifts in their elevated reefs, and of depressions in their embayments. There is some evidence that certain uplifted fringing reefs on the island of Efate, near the center of the group, were formed during pauses in a subsidence that preceded their uplift, and not during pauses in their uplift, as inferred by Mawson. The narrowness of the lagoons enclosed by the barrier reefs that encircle certain strongly embayed islands in this group may be explained by supposing alternations of slow and rapid subsidence, so that the earlier-formed reefs, which began to grow when the subsidence was slowly initiated, were drowned when it was later accelerated; the new reefs thereupon begun on the shoreline of that time would not now stand far outside of the present shoreline, though the shoreline would be strongly embayed because the total subsidence has been large. The absence of reefs around the island of Ambrym is due to its abundant eruptions in recent years, the latest one being in December, 1913. Scattered corals were seen growing on one of its sea-cliffed lava-streams, thus illustrating the initial stage of a fringing reef.

The Great Barrier reef of Australia, the largest reef in the world, with a length of some 1200 miles and a lagoon from 15 to 70 or more miles wide, has grown upward during the recent subsidence by which the Queensland coast has been elaborately embayed, as was pointed out by Andrews in 1902.

A few hours on shore at Raratonga, the southernmost member of the Cook group, sufficed to show that extensive former embayments entering its elaborately carved mass are now occupied by delta plains and perhaps in part by slightly elevated reef and lagoon limestones.

Five islands of the Society group exhibit unequivocal signs of recent subsidence in their intricately embayed shorelines, as has lately been announced by Marshall. The cliff-rimmed island of Tahiti, the largest and youngest of the group, has suffered moderate subsidence after its cliffs were cut, but its bays are now nearly all filled with delta plains; hence a pause or still-stand has followed its latest sinking.

Art. XXI.—*Notes on Black Shale in the Making*; by W. H. Twenhofel.

Much has been written relating to the origin of black shales, but, judging from the divergence of published opinion, no hypothesis has gained a general acceptance. Since this type of deposit occurs at many levels in the geologic column, has often a wide horizontal distribution and is frequently of great thickness, has a fairly definitely assured economic future and has been given an important correlative value, it has furnished the theme of a considerable amount of discussion. It is in the hope of throwing light on the problem of origin that the writer wishes to place on record some observations of black shales in the making and to draw some conclusions from the observations. The locality studied is in Russia on the east shores of the Baltic, and the notes were made during the summer of 1914 while the writer was a member of the Shaler Memorial Expedition to the Baltic Provinces. Before presenting these, it is thought desirable to give a brief review of the more important modes of origin which have been suggested. Also, as a preliminary for discussion, a brief summary of the general characters of black shales will be given.

Hypotheses of Origin of Black Shales.

Doctor John M. Clarke's studies of the Naples and Genesee shales of New York led him to the conclusion that the former and the black bands in the latter "are to be probably considered as pointing to deposition in deep water."* He was largely led to this conclusion by the observations of Andrussow on the conditions of the water, character of the sedimentation and bionomic conditions existing in the Black Sea.† The latter author, in brief, makes the following statement:

> "The Black Sea has a superficial water layer of about 125 fathoms, of less salinity and density than the water in the depths. The yearly increment of surface water is due in great part to the ingress of fresh water. The heavier deep water is derived from a lower current coming from the Mediterranean by way of the richly saline Marmora and Ægean seas, and requires about 1700 years for its removal. In consequence of the salinity and density of the deep water, the Black Sea shows only slight evidence of vertical currents. It is apparent only to a depth of 125 fathoms, and only to this depth, therefore, is there sufficient O for the

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* Clarke, Bull. 6, New York State Museum, 1913, 199–201.

† Andrussow, Guide des excursions du 7 Congrès geolog. internat., No. 27.

support of animal life. The deep water, fed only by the undercurrent, which on account of the high specific gravity due to its salinity, does not mix with the surface water, has insufficient O for animal life. At a depth of about 100 fathoms the separation of H_2S is observable.

"The constant, specifically lighter surface layer over the heavier, richly saline deep water, the lack of O and the separation of H_2S in the depths, thus condition in the Black Sea its peculiar bionomic character, the absence of benthonic animals below the 100-fathom line. In the littoral and shallow water zone benthonic life is present."

"The sediments of the Black Sea are: (1) in the littoral zone and to a depth of about 20 fathoms, accumulations of sandy detritus; (2) to the 100-fathom line, gray blue, sticky mud, from 35–100 fathoms, rich in *Modiola phaseolina*, etc.; (3) in the great depths the bottom is covered with (*a*) very fine, sticky, black mud with rich separation of FeS, abundant remains of plankton, diatoms and with fragments of quite young lamellibranchs (early stages and widely scattered plankton forms), (*b*) dark blue mud; FeS is here in less measure, but in richer quantity are separations of minutely grained $CaCO_3$, making thin banks; skeletons of pelagic diatoms are also abundant."*

This hypothesis probably explains the origin of some black shales, but it does not well accord with the fact that many shales of this type bear evidence of deposition in the shallows, and that many are confined to troughs of considerable length, but little width. The abundant presence of widely distributed pelagic animals shows that the troughs were connected with the great oceans. Furthermore, the separation of iron sulphides is not an evidence of deep water, since Geikie states that "Besides occurring in deep water iron-disulphide is met with in many shallow seas, and on some coasts it cements sand, gravel and shells into a coherent mass."†

Schuchert is another student who has written on the origin of this class of sediment. According to him:

"It is probable . . . that black shales having wide distribution were more often deposits in closed arms of the sea (cul de sacs), or when of small areal extent, as the result of filling of holes in the sea bottom. In all such places there is defective circulation and lack of oxygen resulting in foul asphyxiating bottoms.

"These are the 'halistas' of Walther and the 'dead grounds' of Johnstone. To-day such are the Black Sea and the Bay of Kiel; where sulphur bacteria abound in great profusion. These decompose the dead organisms that rain from the photic region into such suffocating areas, or the carcasses which are drawn

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* Quoted by Clarke, loc. cit.

† Geikie, Text-book of Geology, vol. i, 582, 1903.

there by the slow undertow from the higher ground. These bacteria in the transforming process deposit in the cells sulphur that ultimately combines with the iron that is present and replaces the calcareous skeletons of invertebrates by iron pyrite."*

This explanation, though not widely different from that of Clarke, does not postulate inclosed or relic seas with renewed surface waters, nor waters of great depth; but rather shallow marine conditions and areas devoid of tidal and oceanic currents other than the undertow from higher to lower places. Schuchert makes the additional suggestion that sargasso seas may be places where black shales are depositing; but as such deep oceanic areas appear, so far as vegetal accumulations are concerned, to have little basis in fact,† and certainly little application in general stratigraphy, hypotheses looking to such sources must await further investigation of their deposits.

As graptolites are among the most characteristic fossils of early Paleozoic black shales, it is but natural that Ruedemann should be led to a consideration of the origin of the latter. He takes exception to the hypothesis of an inclosed basin. He states:

> "The black carbonaceous graptolite shales do not indicate conditions of a nearly inclosed basin, such as is now exampled by the Black Sea, for in the latter life exists only near the surface, and the Axonophora, at least, quite surely lived in the more quiet depths, nor would in such a basin be found the great mass of floating seaweed to support the Axonolipa. Many different graptolite zones occur, as a rule, in a small thickness of rock, but sometimes they are also imbedded in coarser sediments. The most essential requisite for the formation of black, fine-grained graptolite shales is, therefore, not the depth, but the tranquillity of the water. The graptolite shales, therefore, indicate a zone between the agitated water, where coarser sediments are deposited, and the dead or currentless water of the deeper sea. Their longitudinal distribution, then, also indicates the direction of a coast line, which has to be sought on the farther side of a parallel band of coarser littoral sediments, and two such flanking littoral bands may be looked for in narrow channels like the Levis channel."‡

Deep-sea dredging apparently supports Ruedemann's contention, for "During the course of the voyage of the Challenger, the approach to the land could always be foretold from the character of the bottom even at distances of 150 and 200 miles. The deposits were found to consist of blue and green muds derived from the degradation of the older crystalline rocks. The blue or dark slate-coloured mud takes its colour from decay-

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* Schuchert, Pop. Sci. Monthly, 598, June, 1910.

† Stevenson, Science, Dec. 9, 1910, 841.

‡ Ruedemann, Bull. Geol. Soc. Am., vol. xxii, 234, 1911.

ing organic matter and sulphide of iron, frequently giving off the odour of sulphuretted hydrogen, and assuming a brown or red hue at the surface, owing to oxidation."*

It is not, however, clear that the facts of stratigraphy are in general agreement with the views expressed by Ruedemann, since there is little universal evidence given by the graptoliferous shales that they were deposited in waters so deep as exists 150 to 200 miles from the shore, although some of them may have so originated.

Among the latest papers dealing with black shale deposition is that of Ulrich. The following extensive quotation from his writings is given because it is about the best published presentation of the characters of black shales. Ulrich expresses his views as follows :

"The graptoliferous black shales of the Levis and Ouachita troughs, in which there are thicker beds of such shale than anywhere else in America, prove as certainly as anything that inclosed and stagnant conditions are not essential to black shale deposition. That most graptolites were pelagic in habit and passed from one open basin into another solely by means of marine currents is universally accepted. They could not have entered a continental basin except a marine current carried them in, and there is no normal possibility of their transportation to the head of a narrow bay. Consequently, when it is established that the deposits in question are confined to narrow strips hundreds of miles in length, it is at the same time proved that they were laid down in channels open at both ends so as to give free passage and egress to the graptolite-bearing currents. Marine thoroughfares like these surely can not be called inclosed nor does it seem possible that they could have become stagnant. And the not infrequent occurrence of intraformational conglomerates in these graptolite shales is almost conclusive proof that the channels were not of unusual depth.

"Obviously, black shale deposition took place under varying conditions of depth and degrees of inclosure. We find similar black muds forming today in the stagnant depths of an isolated Black Sea, and in Paleozoic ages they were deposited in shallow or perhaps comparatively deep channels with evidently perfect circulation as well as broad shallow pans in which, except at times when they were abundantly peopled by certain kinds of marine organisms, circulation may have been very sluggish and imperfect. The vertical distribution of marine organisms in the last suggests that the wide seas which filled the interior basins with black shale may well have been stagnant during most of the time in which such deposits were being laid down. Marine faunas are never found generally distributed through the mass of these black shales. They occur only in occasional thin seams, in which, however, their remains are likely to be very numerous, and the best of these—indeed it may be the only zone with such

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* Geikie, Text Book of Geology, vol. i, 582, 1903.

fossils in hundreds of feet of shale—is usually in the basal foot or two. Although there is no appreciable macroscopic difference between the shale without marine fossils and the matrix of thin bands crowded with them, it yet seems probable that the extinction of marine life is in many cases due to increased fouling of the water by decaying vegetable matter. Marine life could have existed only as long as the upper layers remained uncontaminated."*

Ulrich further suggests "that their origin is in some manner connected with cool temperatures. It is not that glacial climates prevailed at such time, but only that the average, or at least occasional, temperature on the lands adjacent to the continental seas was too low to encourage the development of normal littoral faunas. In other words, that the climates prevailing at times and places of black shale deposition in continental seas were cool enough to render their shores inhospitable to contemporaneous littoral and benthonic life" (loc. cit.). He finds this last suggestion favored by evidence of cool climates having existed during several of the times of black shale formation, but he further admits that the explanation is not so satisfactory as one could wish. To any one familiar with the littoral and benthonic life of northern latitudes the suggestion altogether fails, since on some of the most bleak and inhospitable shores of North America there is no paucity of either plant or animal life in the shallow water zone.

Ulrich's final conclusion is that "great depths and inclosed conditions are seldom if ever essential factors in the origin of black shales," and that none of the black shale deposits in America is comparable in the matter of depth and inclosure of waters in which they were laid down to the black muds in the Black Sea today." and "probably the real cause, if there is any that operated alike in all cases, remains to be discovered."

These different views cannot be made to harmonize and probably there is no need that they should, in that, in all probability, black shale may have originated in each of the different ways postulated; but it does not follow that in these ways only has black shale been formed.

General Summary of Black Shale Characters.

A general summary of the characters of this type of sediment gives: It appears in many cases to be confined to troughs of great length and slight width; it is rich in carbon or hydrocarbons; has the fossils preserved by carbon, pyrite or marcasite; and, in general, shows evidence of quiet deposition, but intraformational conglomerates are not infrequent. Up to the time of the extinction of the group, the graptolites contributed a considerable part of the organic remains now pre-

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* Ulrich, Bull. Geol. Soc. Am., vol. xxii, 358, 1911.

served as fossils. In the lower Paleozoic black shales, these are almost invariably present; though not uniformly distributed, but localized in bands. Species of the littoral or true benthonic forms are comparatively rare. The brachiopods belong almost wholly to species having thin phosphatic shells and these are generally of the non-hinged type. Cephalopods occur rarely, pelecypods are not uncommon locally and always with thin shells, gastropods appear to be quite rare, and trilobites to the time of their extinction occur quite commonly. Heavy shells of any kind are rare.

In the writer's judgment there are two kinds of black shale. One of these is the type so common in the Coal-measures of Kansas and elsewhere. In this kind of black shale, the color appears to a considerable extent to be due to contained carbon not combined with hydrogen. The other type is that rich in hydrocarbon. This variety is well exampled by the Utica as exposed about Ottawa, Canada. And, in any discussion of origin of black shales, the writer believes the two types should be carefully differentiated, as the former is generally of non-marine origin, while the latter is in most cases probably marine.

Black Shale in the Making.

In the province of Esthonia, Russia, there are a number of localities along the shores of the Baltic in which deposits of black shale are now forming. Opposite the city of Hapsal is the long peninsula of Nuckö, at one time an island. Schmidt's map,* published in 1858, so pictures it and he specifically designates it as such; but Lange's map of 1914 shows a low connection with the mainland at the north end. The water between the peninsula and the mainland is brackish; not to a high degree, but similar to that in the Baltic of all this region, although it is sweeter in the bays than outside. At present the bay has a length of about 12 km. and a width at the places to be described of from about 2 to 4 km. Formerly the passage was 15 km. long. Where the widths above given obtain, the bay is bordered on one or both sides for a mile or more by swamp land, some of which lies a foot or two above water-level, but of which fully half lies below this level. There is little doubt that these areas were once a part of the bay and have been filled up in the manner to be described. Much of this swamp land has a heavy growth of coarse grasses and reeds, the latter said to be extensively used by the peasants for thatching roofs. In seeking for a place to cross the bay, it was necessary to somewhat extensively explore the swamp and it was found that the substratum is composed of a very

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* Schmidt: Untersuchungen uber die Silurische Formation von Ehstland, Nord-Livland und Oesel, Archiv für die Naturkunde Liv-Ehst-und Kurlands, (1), xi, 132, 1858.

fine-grained black slime heavily charged with sulphur gas. The reeds growing on the surface, both above and beneath the water, ultimately appear to leave no microscopic signs of their presence, since a few inches below the surface nothing but black mud occurs. Later the bay was crossed by a boat and it was found to be so shallow that the boat was propelled by a pole and the entire bottom was seen to be covered with a similar black slime which also contained sulphur gases. Landing was effected by wading from the boat and it was learned in an extremely disagreeable way that the upper layers of the slime were very soft and permeable and that one sunk nearly to the hips before reaching a bottom firm enough to hold the weight of a man. That compact slime of this kind probably underlies the greater portion of the swampy land on each side of the bay for a considerable depth below the surface is extremely probable.

Farther to the south are the two islands of Oesel and Moon, separated by a body of water with a minimum width of about one mile. It is known as the Little Sound and is open at both ends. The water is quite shallow and at one place the two islands have been joined by a road. Many parts of each shore have extensive deposits of the black slime and it also covers some parts of the bottom and probably most of it.

Near the town of Arensburg on the southwestern corner of the island of Oesel, there is a large bay which has only a narrow connection with the Baltic. At the time of the building of Arensburg Castle (1334), this bay was open to the sea and afforded an excellent harbor. At the present time it is almost completely filled with slime of the same character as that of Lyckholm Bay and is accessible from the sea only to small rowboats. In the town the slime is extensively used for baths, at least three establishments exploiting it for this purpose. The healing properties are said to be very great, but the odor and general appearance would appear to be somewhat repellent. The writer was informed that it is also used at Hapsal for bathing, but this statement has not been verified.

Between the Sworbe, the long southwestern peninsula extension of Oesel, and Oesel proper, there is another narrow sound which is almost completely filled with a similar slime. The width of this body of water is not great and it is not shown on any map which the writer has seen.

Schmidt has briefly referred to these slimes (loc. cited, p. 89) and he states that they are deposited in protected bays in apparent independence of the character of the sea floor and are made from the decomposed remains of animals and plants. He gives as localities additional to those named many parts of the long stretch of coast between Pernau and Hapsal and parts of the north and west coasts of Oesel. The deposits have also been considered by Eichwald,* Schrenck † and Goebel.‡

In Baltische Landeskunde the slime is described as having a more or less dark color and being broth-like to jelly-like when wet. When dried it becomes a firm mass which is able to be cut and affords a valuable fertilizer. Anærobic bacteria appear to have taken a large part in its development. The microscope shows that it contains very small pieces of plant tissue and excretions and the sheddings of animals.§

The macroscopically visible fauna of these deposits is not large and the shells are small. They belong to species which are normally of considerable size; but which, under the brackish water conditions of this part of the Baltic, attain dimensions but little more than a fifth or a fourth so large as the norm. Few examples were seen directly in the shales and they were seen in close contiguity only along the shores of the sound between Moon and Oesel. Four species were collected at this locality. They are *Limnea ovata baltica*, *Mytilus edulus*, *Mya arenaria* and *Cardium edula*; not one of which is over one half an inch long. The shells of each species are very light and float easily and in many instances they were seen on the beach in great numbers. They had been thrown there by high waves, and there is no doubt that they are frequently so introduced in equally great numbers into the slimes.

The strong sulphur content of the slimes should certainly precipitate any iron therein contained as pyrite or marcasite, and this would almost certainly replace the calcite or the shells. The extreme fineness of the muds and the fact that the upper layers are rather fluids than solids are conditions which readily lend themselves to the development of hydrocarbons of various kinds, thus giving rise to a shale rich in these substances.

Another feature of the slime deposits that is of some importance is that they are not generally flanked by littoral or shore deposits. This results from the fact that the vegetation covers the shore to below the water level, thus protecting it from wear and not permitting the segregation of clastic deposits. Hence, if these slimes should fortunately be preserved, they would not be flanked by any clastic deposits as postulated by Ruedemann, except perhaps locally. Also a violent storm might suffice to carry gravel from a local deposit, or from the mouth of the bay or sound and mingle it with the

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* Eichwald, Bull. de Moscou, i, p. 414, 1852.

† Schrenck, Uebersicht des obersilurischen Schichtensystems Liv- und Ehstlands, etc., Lorpat, 1852, p. 102.

‡ Goebel, Archiv für Naturkunde Liv-, Ehst- und Kurlands, 1852, ser. (1), i, p. 113.

§ E. V. Wahl and K. H. Kupfer, Baltische Landeskunde, Riga 1911, p. 242.

slime. But if this should occur, the heavier bowlders would be very apt to sink in the slime for one or two feet, while the smaller ones would remain suspended above.

How thick these slimes are, and what is probably of greater importance, how thick they may become, is not known. In the Lyckholm and Arensburg bays, it appears fairly probable that they may be fully a score or more feet thick and, if slow depression has occurred, there is the probability of an extensive thickness. Further, there should be an extension seaward as the lightness of the slimes readily permits transportation. And it appears that this actually takes place at Hapsal, judging from the strong odor of slime which exists near the water. In respect to area involved it is difficult to give definite quantitative data. Estimations made from Lange's map give the areas of the four localities described above, as having between perhaps 150 and 200 square km. over which the slime occurs, with probably from 75 to 100 square km. having it as a deposit of considerable thickness.

The origin of the slimes is probably related as a first cause to the tranquility of the water in the bays and sounds, since similar deposits are not forming in the open places. Secondly, it is probable that the absence of tides and the character of the climate permits the vegetation to flourish in the manner described. Conditions of a similar character may have obtained in the development of the Paleozoic black shales, but on that point nothing can be said.

There appears to be little doubt that these deposits on compression would form black shales and would have most of the characters typical of such. They would carry a fauna of species with small thin shells and these would probably be largely preserved as pyrite or marcasite replacements. They would probably also occur in great abundance at various levels from being carried in by storms, but be generally rare. It is possible that thin conglomerates would be present; but, if so, it is probable that the coarser bowlders would be below, while above there would be a gradation to finer shales. The shale bands would have no flanking clastic deposits, except locally, and would be long in respect to width, approaching, however, in no way the great lengths of some of the Paleozoic black shales. Furthermore, their extensive distribution in local basins might lead to an inference of continuity of the separate areas, especially if the intervening deposits were covered.

As a conclusion, the writer considers it absolutely certain that black hydrocarbonaceous shale may form in water so shallow that it is but a step to land conditions, and that their presence is by no means an evidence of deep water.

University of Kansas, Lawrence, Kansas

ART. XXII.—*Anodic Potentials of Silver: I. The Determination of the Reaction Potentials of Silver and their Significance;* by JOHN HENRY REEDY.

(Contributions from the Kent Chemical Laboratory of Yale Univ.—cclxix.)

IT is generally recognized that electrode reactions are conditioned by the existence of a more or less definite potential difference between electrode and solution. In general, these reactions consist in (a) the discharge of anions, (b) the formation of cations, or (c) change of valence of ions. The potentials corresponding to these cases are called (a) "deposition" or "discharge" potential, (b) "solution" potential, and (c) "oxidation" (or "reduction") potential. The reactions discussed in this paper belong wholly to the first two cases.

As it is desirable to have a term to include all of these and to represent, in general, the potential at which a reaction takes place, the expression "reaction potential" will be used.* In all cases this potential is dependent upon temperature and concentration of the substances or ions involved. When electrolytes, such as sulphuric acid with platinum electrodes,† show two or more reaction potentials, it is generally assumed that each represents the beginning of a new reaction.

The Determination of Reaction Potentials.—Since the reaction potential is the potential difference that must exist between an electrode and a solution in order that the reaction may begin, it can therefore be found by making the metal one of the electrodes of an *electrolytic* cell, and determining (by comparison with some standard electrode) the potential at which an appreciable current begins to pass. This potential is most accurately measured by the third electrode method,‡ in which no current flows in the subsidiary circuit, thus insuring a constancy of potential for the reference electrode. This method is suitable for all cases, whether the action is reversible or not, and has been used exclusively in this work.

LeBlanc§ has shown that, for reversible electrodes, the reaction potential is the same as the potential shown by the metal when immersed in the solution, and hence may be readily determined by electromotive force measurements. This method, however, can not be used when the action is irreversible, owing to polarization effects.

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* The term "electrode decomposition potential" used by some writers is practically synonymous with "reaction potential," but, in the opinion of the writer, is open to objection. Preferably "decomposition potential" should be limited to the potential drop across the cell required to effect electrolysis.

† Le Blanc, "Electrochemistry," 1900, p. 307.

‡ Cf. Bose, Zeitschr. Elektroch., v, 153.

§ Zeitschr. phys. Chem., xii, 333.

Reference Electrodes.—As a standard electrode for most of the measurements, a mercury-mercurous sulphate electrode was used, the electrolyte being 0·5 molar H_2SO_4. The potential of this electrode was found by trial to be +·679 volts, referred to the hydrogen normal electrode as 0.* This value for the mercurous sulphate electrode is the same as that found by Wilsmore.† It was found to be quite constant, no sensible change in its value appearing after standing several months.

With alkaline solutions a mercuric oxide electrode was used. This consisted of mercury covered with a layer of yellow mercuric oxide in contact with a normal solution of sodium hydroxide. Its potential was found by experiment to be +·112 volts. Wilsmore‡ assigns it the value +·110 volts. The potential was found to change slowly,§ so the electrode was always freshly prepared and compared with a standard calomel electrode before using.

Apparatus.—Figure 1 is a diagram of the apparatus used. The electrolytic cell B was a glass cylinder about 14^{cm} high and 7^{cm} in diameter. It was closed by a rubber stopper through which the electrode connections were introduced. These consisted of heavy platinum wires, fixed in glass tubing where they passed through the stopper, and terminated in hooks from which the electrodes were suspended.

The cathode C was a piece of bright sheet platinum, 21×50^{mm}. The anode A was of sheet silver, 35×38^{mm}. This was purchased for "fine silver," and test showed it to be free from copper. Each electrode had a wire stem ending in a loop for ready attachment to the hooks mentioned above.

The main circuit was operated by the lead storage cell L, as indicated in the diagram. R was a sliding resistance, by means of which the voltage of the electrolyzing current could be altered. A sensitive Hartmann & Braun galvanometer G of the type furnished for use with a platinum thermocouple was placed in the main circuit to serve as a current indicator, one scale division (about 1^{cm}) representing ·009 milliamperes. When larger currents were to be measured, the Weston milliammeter M could be substituted for the galvanometer by shifting the switches S and S′.

F was the third electrode, and D an intermediate vessel containing a solution to eliminate diffusion potentials. For this purpose saturated potassium chloride solution was used in all cases except those in which it was necessary to guard against the introduction of traces of chlorides into the solution. In such cases saturated ammonium nitrate solution was used in

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* Throughout this paper, all potentials are referred to this standard.

† Zeitschr. phys. Chem., xxxvi, 94.

‡ Ibid., xxxv, 325.

§ Cf. Ostwald-Luther, "Messungen," 1910, p. 445.

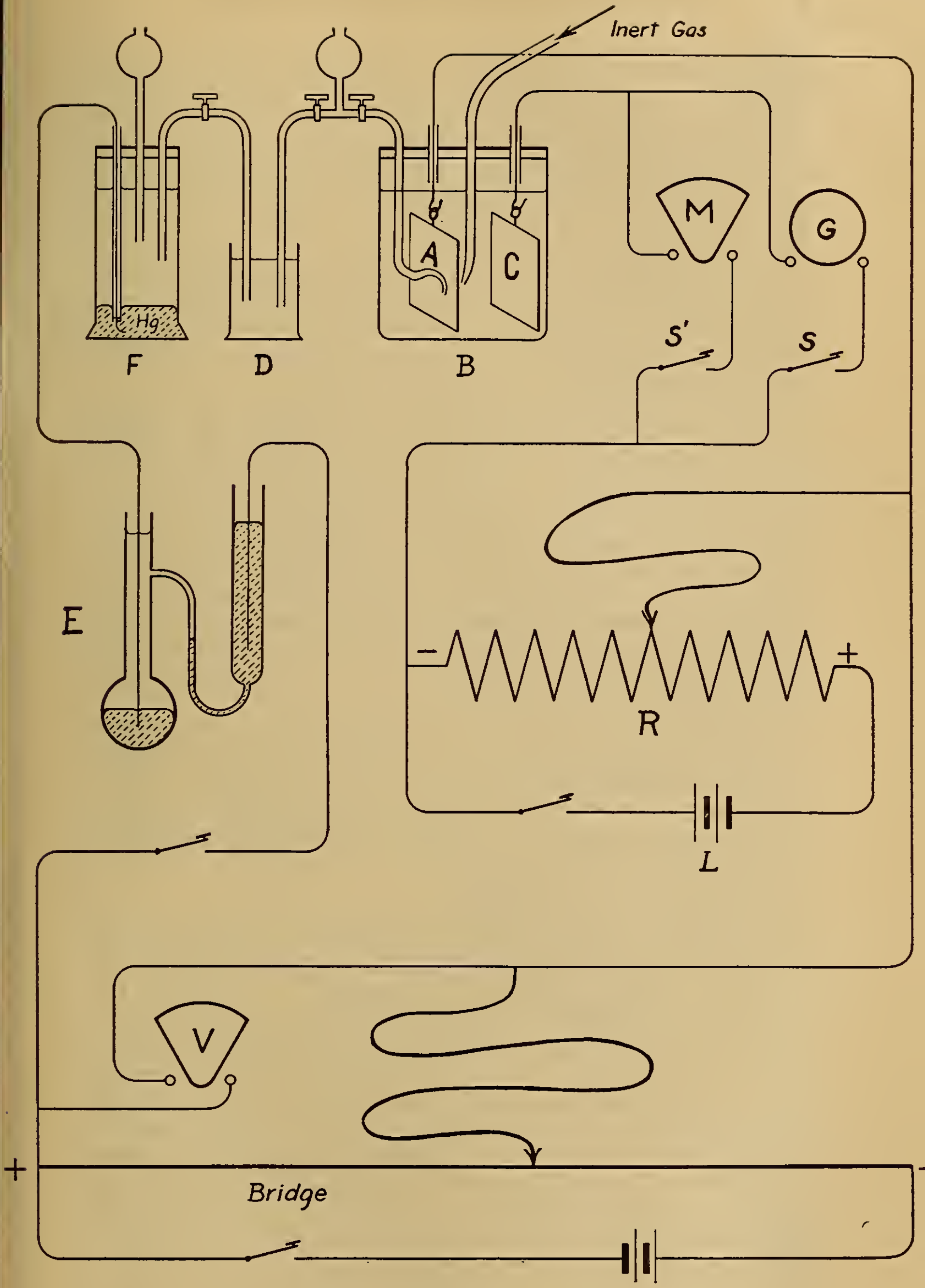

FIG. 1. Diagram of apparatus.

place of the potassium chloride. A comparison of the results obtained by the use of these two solutions showed that their effects were practically the same, anodic potentials with saturated ammonium nitrate being found to be higher than those with the saturated potassium chloride by about ·002 volts. No change in this intermediate solution was ever made during any series of measurements, so that any error due to this difference could be disregarded.

The arrangement of bulbs and stopcocks between the electrolytic cell B and the third electrode F was devised to provide for convenient filling of the connecting tubes, and to prevent mixing of the solutions by diffusion and gravity. Potentials were measured with the stopcocks closed.

In the subsidiary circuit, E was a capillary electrometer which was used as a null instrument. K was a lead storage cell, connected with the bridge as indicated. In order to obviate calculations as well as errors due to changes in the storage cell operating the electrometer circuit, a Weston voltmeter V with a range of 3 volts was placed in a shunt between the positive end of the bridge and the sliding contact, the point of balance being found as usual by the electrometer, and the potential then read directly on the voltmeter. This combination was carefully calibrated against a cadmium cell, and the corrections so determined have been applied to all voltmeter readings recorded below.

Experimental Procedure.—The general method for determining reaction potentials is to subject the cell to a gradually increasing voltage, and to plot on coördinate paper the electrode potentials as abscissæ and the corresponding current strengths as ordinates. A graph is drawn, and the potential corresponding to the appearance of an appreciable current is taken as the reaction potential.

When the reaction is reversible, the curve has the general form typified by the graph for 0·1 molar KCl (see fig. 2), for which the reaction potential is seen to be ·285 volts. The portion of the graph below the horizontal axis represents the behavior of the electrode as a cathode; that above, the behavior as an anode. There is no discontinuity upon passing from one region to the other. On the other hand, the line is quite straight and makes an angle of nearly 90° with the potential axis, indicating that the electrode is almost perfectly reversible.

When the reaction is not reversible, the shape of the curve is different, since for a greater or less range of potential the current is practically zero; that is, the anodic behavior is not continuous with the behavior as a cathode. The curve for 0·5 molar sulphuric acid (see fig. 2) is typical of this class. No cathode current is found—at least within the range of potential used—so that the curve lies wholly above the horizontal axis. For non-reversible electrodes, as Ostwald[*] has pointed out, this method gives definite values for reaction potentials only when a product of the reaction is insoluble—that is, a precipitate or a gas. When the products are soluble, the current does not appear abruptly; the slight residual current (the "Reststrom") merges into a much larger current (that is, "current of constant polarization") with a gradual bend, owing to such influences as diffusion, stirring and the like. In the present investigation this was notably the case in the current potential curves obtained for silver anodes in solutions containing such anions as SO_4'', NO_3', etc.; or in general, those which form simple soluble silver salts. In such cases the tangent to the graph was drawn at the point of greatest curva-

Fig. 2.

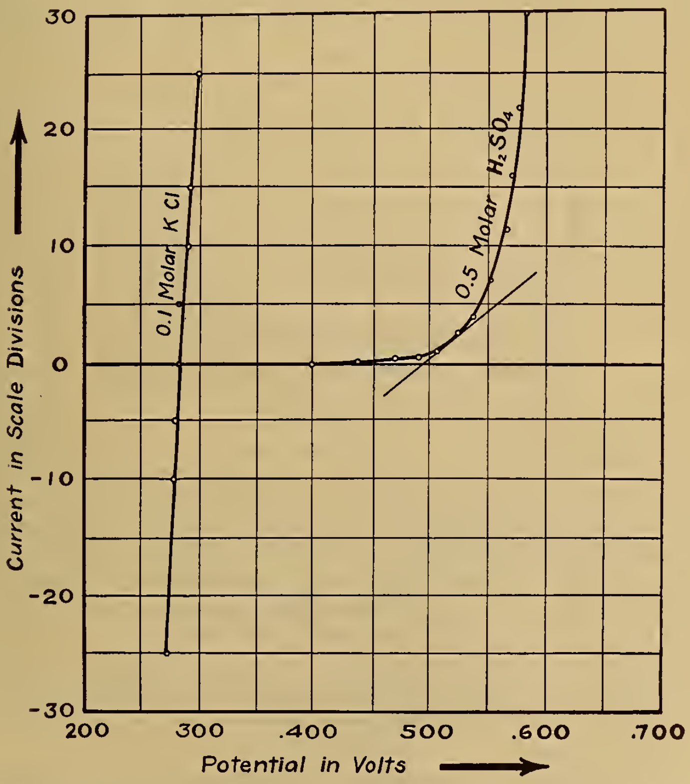

Fig. 2. Reaction potentials of silver with 0·1 molar KCl and 0·5 molar H_2SO_4.

[*] Ostwald–Luther, "Messungen," 1910, p. 455.

ture, and the corresponding potential taken as the reaction potential.

This method was justified by the following experiment: A silver anode in 0·5 molar H_2SO_4 was given a definite potential—say, ·500 volts—which was kept constant by adjusting from time to time. Oxidation by the air was prevented by stirring the solution vigorously with a jet of hydrogen. At the end of several hours the solution was tested for silver with hydrochloric acid, and it was found that no silver had dissolved. The anode potential was then raised, and after several hours the test for silver in the solution was again made. Following this method silver was found to dissolve between ·515 and ·525 volts. More careful experimentation fixed ·521 volts as the reaction potential. The probable error in this determination is believed not to exceed 2 millivolts.

FIG. 3.

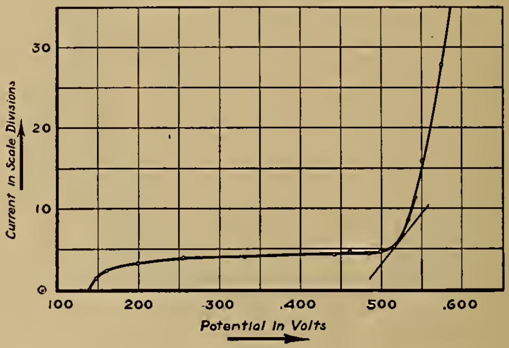

FIG. 3. Reaction potentials of silver with dilute KI in 0·5 molar H_2SO_4.

Since the current-potential curves for all solutions of this class with silver anodes are very similar—in fact, almost superposable—it has been assumed that the above method may be used in all cases.

No hypothesis is offered as to the nature of the residual current which passes below the reaction potential as above determined. So far as could be determined by means of chemical tests, no solution of silver takes place during its passage.

Stirring.—The reaction potentials of silver seem to be indifferent to the stirring agent. No appreciable differences were found when the solution was stirred (a) mechanically by means of a rotating anode, and (b) by means of a jet of gas, such as hydrogen, carbon dioxide, or filtered air, issuing close to the anode. Air, however, is not suitable for stirring acidified iodide solutions, on account of oxidation effects.

Coated Electrodes.—When a reaction takes place with the formation of an insoluble compound on the anode, it was found that the reaction potential (as will be discussed in full later) depends on whether the anode is bright, or whether it is already coated with the insoluble compound in question.* Bright electrodes give potentials which are not definite and

FIG. 4.

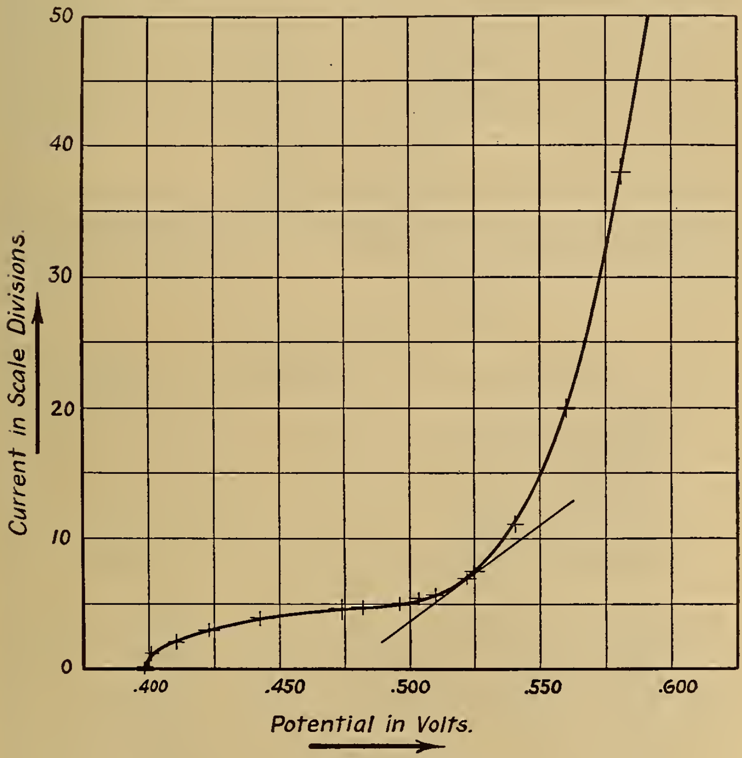

FIG. 4. Reaction potentials of silver with 0·5 molar $KBrO_3$.

change rapidly, but with coated electrodes the potential is constant and always reproducible. For this reason reaction potentials for reactions which involve the formation of insoluble products have been determined on coated electrodes.

These coatings were usually formed electrolytically by making the electrode the anode in a cell containing the potassium compound of the anion required. It was then thoroughly washed and dried at 150°. In the case of the halides, anodes which were coated chemically by standing in solutions of the

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* Verh. Ges. deutsch. Aertze, 1913 (1914), ii, 361.

free halogens gave exactly the same potentials as those coated by electrolysis.

Curves with More than One Flexure.—Some of the curves obtained showed two flexures, as in fig. 3, which gives the curve for a very dilute solution of potassium iodide in 0·5 molar sulphuric acid. The first reaction potential is at ·136 volts, and a second at ·521 volts. These two different potentials are best explained by assuming that the first one represents the *deposition potential* for I′–ions of that particular concentration; but as a higher anodic potential is impressed, the current density reaches a limit on account of the reduction of the I′–ion concentration close to the anode, and with increasing potential remains approximately constant until the potential is reached at which silver begins to dissolve. A similar explanation holds for the BrO_3'–ion curve (fig. 4).

Reaction Potentials with Various Electrolytes.—The above method was used for the determination of the reaction potentials of a large number of solutions. The following is a partial list of the results obtained:

TABLE I. *Reaction Potentials.*

Electrolyte used	Molar concentration	Reaction potential
Sulphuric acid	·5	·521 volts
Sodium sulphate	·5	·523
Potassium sulphate	·25	·521
Zinc sulphate	·5	·521
Magnesium sulphate	·5	·522
* Copper sulphate	·5	·550
* Mercurous sulphate	·0016	·660
Nitric acid	1	·520
Potassium nitrate	1	·521
Sodium nitrate	1	·520
Phosphoric acid	·333	·521
Disodium phosphate	·333	·523
Oxalic acid	·5	·520
Ammonium oxalate	·5	·521
Acetic acid	1	·522
KCl in ·5M. H_2SO_4	1	·222
KBr in ·5M. H_2SO_4	1	·077
KI in ·5M. H_2SO_4	1	—·152
Sodium hydroxide	1	·346
Potassium hydroxide	1	·348
Sodium thiosulphate	·5	—·147
Potassium cyanide	1 (about)	—·611

* The anomalous behavior of solutions of copper and mercury will be discussed later.

Influence of Concentration on Reaction Potentials.—In the preceding table, it is noticeable that silver shows the same reaction potential (about ·521 volts) with a large number of anions. In such cases the reaction potential is independent of the concentration of the anion (see Table II), which seems to show that the rôle of the latter is negligible, or at least of secondary importance.

TABLE II. *Reaction Potentials of Various Concentrations of Sulphuric Acid.*

Molar concentration	Reaction potential
1·0	·521 volts
·5	·521
·25	·522
·1	·521

On the other hand, with anions which showed reaction potentials lower than ·521 volts, concentration effects were marked.

TABLE III. *Concentration Effects in Solutions of Low Reaction Potentials.*

Concentration in moles	KCl in ·5M H_2SO_4	KBr in ·5M H_2SO_4	KI in ·5M H_2SO_4	NaOH in M $NaNO_3$
1	·222	·077	—·152	·346 volts
·1	·285	·139	—·087	·400
·01	·350	·200	—·027	·462
·001	·413	·259	·035	·484
·0001	·467	·319	·099	·500
·00001	·510	·391	·183	·508

All of the above data were found to be definite and reproducible within a limit of one millivolt, excepting those for the ·00001 molar concentration, where the experimental error is necessarily relatively great, and the results are consequently slightly uncertain.

Deposition Potential.—The low reaction potentials of silver with the halogen ions, the cyanide ion, the thiosulphate ion, and the hydroxyl ion might be explained by the assumption that these ions give up their electric charges to silver very readily, and are deposited on the silver anode. From this point of view, the potential necessary to deposit an ion on an electrode is regarded as its *deposition potential* and varies with the concentration of the ion and the metal of the electrode. This must be distinguished from the discharge potential on unattacked electrodes, where the discharged ions combine with one another, or react with the solvent or other materials present. Deposition potentials on attacked electrodes lie below the discharge potentials on inert electrodes, since they are less by an amount which must correspond in some degree to the energy changes involved in the formation of the compound.

It is very noteworthy that in the case of silver the substances formed by deposition of anions are the ones which furnish low $Ag^{\cdot}$-ion concentrations, owing to low solubility or to the formation of complexes. Further, the deposition potentials and ionic concentrations are in the same order. This suggests, to say the least, that the ionic concentration of the silver may be the determining influence in these reaction potentials. According to the deposition theory, it must be assumed that, in the case of the thiosulphate and cyanide ions, these anions are first deposited on the silver, and the silver salt thus formed later reacts with the excess of the electrolyte to form the final complexes.

Significance of the Potential ·521 Volts.—The reaction which takes place at the potential ·521 volts, which is the highest anode potential observed in solutions containing no $Ag^{\cdot}$–ions, amounts in practice to the solution of silver. This action seems to take place irrespective of the anions present or their concentration, provided they do not belong to the group which gives low reaction potentials, as mentioned above. If there is present at this potential a small concentration of the ions of an insoluble silver compound, as OH'–ion or Cl'–ion, a precipitation occurs, not only upon the electrode, but in the solution. In view of this behavior, this maximum potential may be called the *solution potential* of silver.

The mechanism of this reaction can be explained from three different points of view:

(*a*) Anions of the solution are discharged on the silver, a large number of anions having the same deposition potential, ·521 volts.

(*b*) Hydroxyl ions from the water are discharged, and the silver hydroxide thus formed is instantly neutralized by the acid formed at the same moment.

(*c*) Silver sends ions into solution at this potential.

The first theory seems unlikely, since such a coincidence of discharge potentials for several anions would be remarkable indeed. And the additional fact that the potential is not influenced by change of concentration (see the case of sulphuric acid, page 282) is a further argument against it. A third objection is found in the fact that an electrolyte may show two different reaction potentials, and yet contain only a single kind of anion (not counting the OH'–ion from the water.) Such a case was found in 0·5 molar potassium bromate. (See fig. 4.) An anodic reaction potential first appears at ·398 volts, and the flexure at ·521 volts indicates that at that potential a second reaction has been superposed upon the first. The lower potential may in all probability be taken to mean the deposition of BrO_3'–ions, exactly analogous to the deposition of the halides and other anions which form silver compounds of low solubility. The second potential, ·521 volts, therefore must mean either the discharge of the hydroxyl ions of the water (hypothesis *b*), or the direct formation of silver ions (hypothesis *c*).

Hypothesis *b* assumes that hydroxyl ions from the water are discharged on silver at ·521 volts, forming AgOH (or Ag_2O), and that this reacts with the hydrogen ion, also formed by the dissociation of water, to form water and silver ions,—

$$AgOH + H^{\cdot} \longrightarrow H_2O + Ag^{\cdot}.$$

This hypothesis is open to the following objections: (i) The reaction is uninfluenced by acidity since acids and their neutral salts give the same reaction potentials. (See Table I, page 288.) If this hypothesis were correct, the theory of equilibrium between the ions and the electrode would require that the potential for acids should be much higher than for neutral salts, since in the acids the concentration of the hydroxyl ion must be very low. This should mean a difference of ·4 volts between the potential in an acid of normal concentration and that of one of its neutral salts. (ii) Neutral solutions were electrolyzed on silver anodes, and no acidity was developed at the anode, as would be expected if hydroxyl ions were precipitated. Nor was there any evidence of the formation of silver oxide, either by its dark color or by loss in weight on ignition.

The following considerations appear to favor the theory that the silver goes directly into solution in the form of silver ions (hypothesis *c*): (i) If a very dilute solution of hydrochloric acid is electrolyzed at an anode potential of less than ·521 volts, silver chloride is formed on the anode, and no turbidity appears in the solution. But if the potential is raised above ·521 volts the solution at once shows the characteristic opalescence. This effect is made all the more striking by avoiding agitation of the electrolyte. In this case a white cloud soon envelops the anode and slowly diffuses outward into the liquid. Within this region of precipitation $Ag^{\cdot}$–ions seem to be in excess, and as they diffuse outward are precipitated by the Cl'–ions. A similar phenomenon was produced with alkaline solutions. (ii) The theory of the direct formation of $Ag^{\cdot}$–ions is made more probable by thermal data. According to the theory of the primary electrolysis of water (see *b*, page 290), the solution of silver would take place in stages, which, with their heats of reaction, would be represented by the following equations:

$$2OH' \longrightarrow \tfrac{1}{2}O_2 + H_2O - 108{,}800 \text{ cal.*}$$
$$2Ag + \tfrac{1}{2}O_2 \longrightarrow Ag_2O + 5{,}900 \text{ cal.†}$$
$$Ag_2O + H_2SO_4.Aq \longrightarrow Ag_2SO_4.Aq + H_2O + 14{,}490 \text{ cal.†}$$

$$2OH' + 2Ag + H_2SO_4.Aq \longrightarrow Ag_2SO_4.Aq + 2H_2O - 88{,}410 \text{ cal.}$$

Compared with the energy required to effect in this way the solution of two gram equivalents of silver, the heat required to form two gram ions of silver by direct ionization is only 46,600 calories.‡ From this it appears that silver most probably passes into solution by ionization, and not by the discharge of the hydroxyl ions of the water. (iii) The direct ionization of silver must be postulated to explain the equilibrium between a silver electrode and $Ag^{\cdot}$-ions, as in the case of all other electrodes of the first class. The necessity in that case should at least count for probability in the case of solution potentials.

The relation between the "solution potential" and the "electrolytic solution pressure" of silver is yet undetermined. Without doubt, other influences, such as electrostatic attraction, are operative in determining the solution potential.

In this connection, the energy relations of solutions which show two reaction potentials come up for discussion. In addition to potassium bromate, this behavior was found in dilute solutions of chlorides, bromides, iodides and hydroxides. In the case of the bromate curve, for example, the question presents itself: Since in both reactions the same substance is formed (i.e., silver bromate), why should the potential be different, when the latter is understood to be a measure of the chemical work done?

The answer is, that the lower potential doubtless represents the work done in depositing a bromate ion of that concentration on silver, while the higher potential represents the work done in forming a silver ion. To be sure, the silver ion is at once precipitated by a bromate ion of the solution, forming the same $AgBrO_3$ as before. It then follows that the total change in free energy is the same in both cases; but in the latter case the combination of the silver radical and the bromate radical occurs *in solution*, and not on the electrode. Hence the difference in potential may be explained upon the assumption that the energy of ionic combination appears as *heat*, and not as electrical energy.

Concentration Effects in the Light of the Nernst Formula.—Figure 5 shows the influence of concentration on the anodic

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* Ostwald, Grund. allg. Chem., 1909, p. 309.

† Thomsen, Thermoch. Untersuch., III, p. 381.

‡ Ostwald, Grund. allg. Chem. 1909, p. 309.

reaction potentials of silver with the halogen and hydroxyl ions. The potentials are plotted as ordinates and the logarithms of the dilutions of the ions as abscissæ. For dilutions up to 1000 liters the ionic concentration of the anions was calculated from conductivity data; for dilutions of over 1000 liters the ionization is assumed to be complete. These potentials were

FIG. 5.

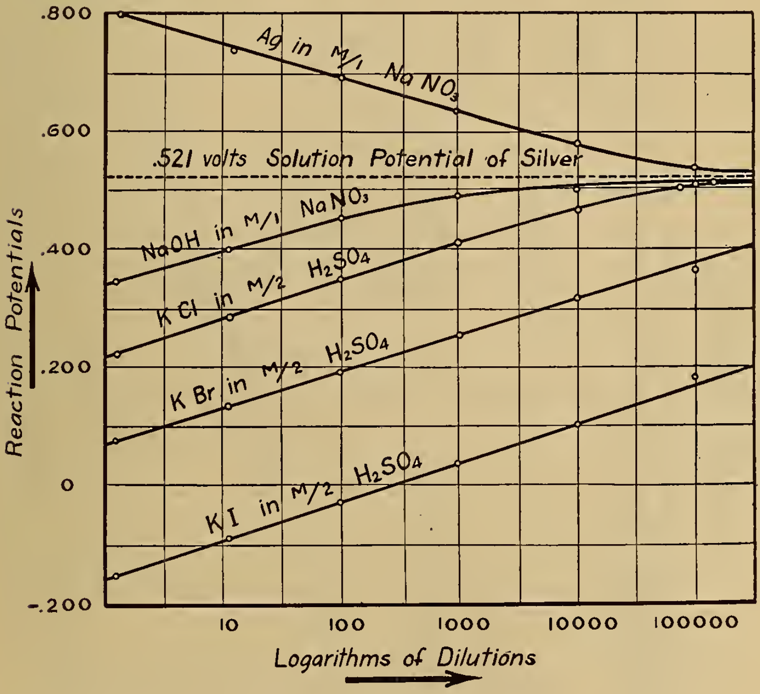

FIG. 5. Effect of concentration on reaction potentials on silver anodes.

obtained on silver anodes coated electrolytically with the silver compound corresponding to the anion of the solution.

The lines for bromine and iodine ions are apparently straight; that is, the potential is a logarithmic function of the dilution, although the slope is greater than would be expected from the Nernst formula. Instead of ·0585 (for 22°, the average temperature of the experiments), the slope appears to be ·0646—about 10 per cent higher than the theoretical value. No explanation of this deviation is offered. At ordinary concentrations (1 to ·001 molar) the lines for chlorine and hydroxyl ions are straight, just as in the case of bromine and iodine ions. But at higher dilutions the increase of potential

FIG. 6.

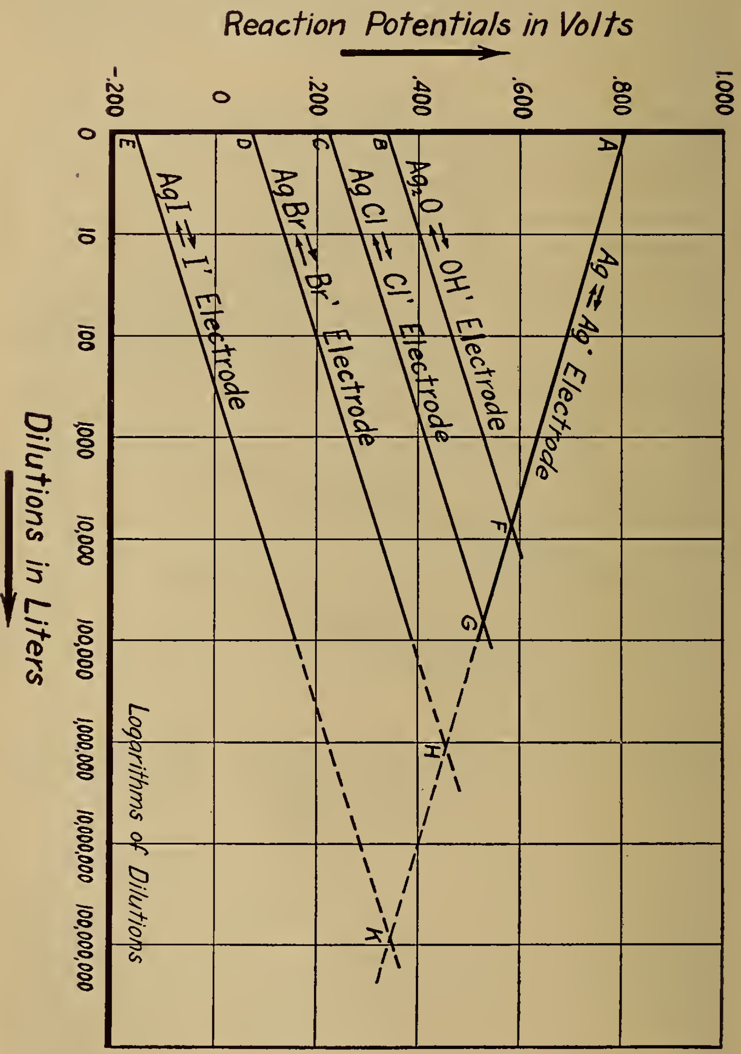

FIG. 6. Solubilities of silver compounds.

with dilution falls off very markedly, so that their lines become almost horizontal. They seem to approach the solution potential of silver (represented by the dotted line) asymptotically and the deviation from the simpler behavior of the other two anions seems to be due in some way to the proximity of the potentials to this limiting value. Presumably, the bromine and iodine lines would show a similar curvature if it were possible to obtain satisfactory data for the extreme dilutions that would be required.

Solubility of the Oxide and Halides of Silver.—Figure 6 represents in a comprehensive way the effects of the concentration of five different ions upon the reaction potential of a silver electrode. The line AK shows the potentials of silver in contact with a solution containing $Ag^{\cdot}$-ions; that is, when it functions as an electrode of the first class. The three lower lines show the behavior of AgCl, AgBr and AgI electrodes,—electrodes of the second class. By extending the lines for the anions according to a logarithmic formula, they cut the upper line at F, G, H, and K. These intersections are the points where the silver may be regarded as an electrode of either class, since they lie on both loci. Further, at these points the cation and the anion have the same concentration. That is, they represent saturated solutions of the silver compounds in question. At the high dilutions here represented, ionization may be considered to be complete. In brief, assuming that the potential is a logarithmic function of the dilution, the solubility of the silver compound in question may be estimated by noting the ionic concentrations corresponding to these intersections. In the case of the hydroxyl and chlorine ions, these intersections were actually realized by determining the cathodic reaction potentials in solutions saturated with silver oxide and silver chloride, respectively. For bromine and iodine ions the intersections were obtained by extrapolation.

Below are the values of the solubilities found in this way compared with those by other methods:

TABLE IV. *Solubilities of Silver Compounds.*

Silver compound	Graphic method	Nernst formula	E. M. F. method	Conductivity method
Ag_2O	$\cdot 6 \times 10^{-4}$	$\cdot 5 \times 10^{-4}$	$\cdot 9 \times 10^{-4}$	$1{\cdot}0 \times 10^{-4}$
AgCl	$1{\cdot}4 \times 10^{-5}$	$\cdot 9 \times 10^{-5}$	$1{\cdot}3 \times 10^{-5}$	$\cdot 9 \times 10^{-5}$
AgBr	$7{\cdot}0 \times 10^{-7}$	$5{\cdot}5 \times 10^{-7}$	$6{\cdot}6 \times 10^{-7}$	$7{\cdot}0 \times 10^{-7}$
AgI	$1{\cdot}0 \times 10^{-8}$	$\cdot 6 \times 10^{-8}$	$1{\cdot}0 \times 10^{-8}$	$1{\cdot}5 \times 10^{-8}$

It will be noticed that the results obtained in this way (see column above, headed "Graphic Method") agree very well with those by the other methods. The somewhat higher values may be due to the presence of the solvent sulphuric acid.

Effect of Deposits of Silver Compounds on the Anode.—In general, the presence of a coating of a silver compound on a silver anode raises the reaction potential for solutions containing the corresponding anion. This is shown in the following table of reaction potentials for the halogen ions:

TABLE V. *Effect of Coating on Anodes.*

Solution	Bright silver anode	Coated silver anode	Elevation
M. KCl in ·5M. H_2SO_4	·234	·222	·012 volts
M. KBr in ·5M. H_2SO_4	·028	·077	·049
M. KI in ·5M. H_2SO_4	—·175	—·152	·023

Evidently the effect of the coating of silver halide is to oppose the discharge of that particular halogen ion—a behavior identical in effect with the so-called electrolytic solution pressure of the anion of the insoluble compound in electrodes of the second class.

Boettger,* in a recent paper, reports that he found the same elevation, though he does not appear to have isolated and measured it.

The amount of the deposit—provided it exceeds an exceedingly thin layer—seems to have no influence on the potential. The approximate thickness of the layer necessary to make the electrode function normally as an electrode of the second class was determined in the following way: A silver electrode, 35×38^{mm}, was made the anode in a molar solution of potassium chloride until it gave the same potential as a coated one. From the gain in weight (assuming that the density of silver chloride is 5·56) the average thickness of the layer was calculated to be $2{\cdot}4 \times 10^{-3mm}$. Below this limit the potential is indefinite, and lies between the values for bright and coated electrodes.

Influence of Free Halogens.—Free halogens exert a strong depressing action of the reaction potential of silver, as is shown in the following way: Solutions of bromine and iodine were made by shaking the free halogens with 0·5 molar sulphuric acid. These may be considered approximately saturated. Using in these solutions the coated silver anodes as in the previous experiments, reaction potentials of ·259 volts and ·357 volts, respectively, were obtained. Compared with the reaction potential of 0·5 molar sulphuric acid (·521 volts), these represent lowerings of ·262 and ·164 volts. Undoubtedly the reaction in such cases is to a large degree molecular, as for example, $2Ag + Br_2 \longrightarrow 2AgBr$; and as such may be assumed to have no effect on the potential. The lowering of the poten-

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* Verh. Ges. deutsch. Aertze, 1913 (1914), II, 361.

tial is to be attributed to the halogen ions, produced by the hydrolysis of the free halogen, according to a reaction of the type, $Br_2+H_2O \rightleftarrows H^{\cdot}+Br'+HOBr$.

The same assumptions explain very satisfactorily the rise in potential which was found to take place with silver electrodes in acidified iodide solutions upon standing in contact with the air. Part of the hydriodic acid in the solution is oxidized to free iodine, which combines with silver to form silver iodide. Besides the reduction of the iodine content of the solution in this way, the I′-ion concentration is further diminished by the fact that some of the iodine passes into the form of free halogen and hypoiodous acid, both of which have no effect on the potential. In brief, oxidation amounts to a decrease in I′-ion concentration.

Influence of Cations on Reaction Potentials.—As is seen in the table of reaction potentials on page 288, all sulphates have the same reaction potential of ·521 volts except those of copper and mercury. With solutions of these metals the results were unexpectedly high. Moreover, silver anodes in these solutions behaved abnormally in that their potentials were indefinite, and showed a tendency to rise, even during the course of a determination. Upon examination of the silver electrodes after such experiments it was found by means of chemical tests that some of the less noble metal had been deposited on the silver. This points to the following reactions taking place, at least to a small degree:

$$2Ag + Cu^{\cdot\cdot} \rightleftarrows 2Ag^{\cdot} + Cu.$$
$$Ag + Hg^{\cdot} \rightleftarrows Ag^{\cdot} + Hg.$$

The progressive increase in the reaction potential may be accounted for in some degree by the appearance of silver ions in the electrolyte. That this small increment of the Ag·–ion concentration should cause such large changes in the reaction potential seems very surprising. It is much more likely that this elevation is mainly due to the formation of solid solutions of copper and of mercury, respectively, in silver. As has been pointed out by Foerster,* the solution of a small amount of a less noble metal (here copper and mercury) in a more noble metal may diminish the electrolytic solution pressure of the latter, just as the presence of a small amount of dissolved substance reduces the vapor pressure of the solvent, even though the solute in the pure state may have the higher vapor pressure. For example, a small amount of ether dissolved in a large amount of water may raise the boiling point of the latter. In a perfectly analogous way, the potential of silver may be raised

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* Elecktrochemie, 1905, p. 208.

by the presence of very small amounts of the baser metals in the form of solid solutions.

Outside of such cases as copper and mercury, the cations of metals less noble than silver seem to have no effect upon the reaction potentials of silver. Finally, it was found that the presence of the nobler metals, as platinum and palladium, in contact with the silver anode exerted no perceptible influence on the potential.

Summary.

1. The term "reaction potential" is used to designate the potential difference that must exist between a metal and a solution for a definite action to begin. This potential is best determined by the third electrode method.

2. For polarizable silver electrodes, where the products of the reaction are soluble, the point of greatest curvature on the current-potential graph may be taken as the reaction potential.

3. A large number of electrolytes show the same reaction potential (·521 volts) with silver anodes, regardless of their concentration. This value is interpreted as the "solution (or ionization) potential" of silver.

4. Reaction potentials below ·521 volts appear in cases where the silver compound formed is insoluble or contains the silver largely in the form of complex ions. These "deposition potentials," except in the neighborhood of the solution potential of silver, are logarithmic functions of the dilutions, as would be expected from the Nernst formula for electromotive force. However, the increase in the reaction potential with dilution was found to be somewhat greater than would be expected from theoretical considerations.

5. Certain electrolytes were made to show two reaction potentials, the lower one due to the deposition of the anion, the other (·521 volts) due to the solution of the silver.

6. Electrodes coated with the insoluble silver compound corresponding to the anion of the solution show higher deposition potentials than do electrodes of bright silver.

7. As a rule, the presence of cations of other metals was found to have no effect on the reaction potentials of silver. In the case of the cations of copper and mercury, however, silver shows abnormally high solution potentials. It is suggested that these metals may form solid solutions with silver, with a resultant lowering of its electrolytic solution pressure.

Art. XXIII.—*The Use of Compensators, Bounded by Curved Surfaces, in Displacement Interferometry*; by Carl Barus.*

1. *Introduction.*—The method of increasing the sensitiveness of the displacement interferometer by increasing the dispersion of the grating readily suggests itself. Unfortunately the interference pattern loses sharpness in the same ratio and ultimately becomes too diffuse for practical purposes. Similar sensitiveness is secured when the glass and the air paths of the component beams of light are respectively identical, with the same inadequacy in the huge mobile figures, for the purpose of adjustment. In fact, if for simplicity we consider the incidence normal ($I = R = 0$, linear interferometer), the sensitiveness becomes

$$d\theta/dn = \lambda^2/\{2eD \cos\theta.\ ((\mu + 2b/\lambda^2) - N)\}$$

where θ is the angle of diffraction for the wave length λ, e the thickness of the plate of the grating, μ its index of refraction, D the grating space, n the order of the fringe and b, N constants. Hence other things being equal, $d\theta/dn$ increases as D and e grow smaller, where $e = 0$ is obtained by a compensator counteracting the thickness of the plate of the grating.

It occurred to me that the difficulty of diffuse interference patterns might be overcome, in part, by the use of compensators with curved faces, when the case would become similar to the conversion of the usual interference colors of thin plates into Newton's rings. Naturally a cylindric lens with its elements normal to the slit is chiefly in question, though an ordinary lens also presents cases of interest because of the easy conversion of elliptic into hyperbolic patterns and the lens is more easily obtained.

Other methods were tried. For instance in using a Fresnel biprism with its blunt edge normal to the slit, two sets of interference patterns, one above the other in the spectrum, are obtained. When the blunt edge is parallel to the slit, either side of the prism gives its own interferences, but they cannot be made clearly visible at the same time. A doubly reflecting plate or a *thin* sheet of mica covering one half of the beam will produce two intersecting patterns, but these also are of little use for measurement. A very promising method, however, consists in the use of compensators of equivalent thickness, but of different dispersive powers, crown and flint glass, for instance. These experiments are in progress.

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* Abridged from a forthcoming Report to the Carnegie Institution, of Washington, D. C.

2. *Lens systems.*—If but a single compensator is to be used, i. e. compensation in one of the component beams only, the lens in question must be of a very small focal power; otherwise the adjustment will be impossible, as the two direct images of the slit will be in very different focal plains. Moreover the focal power should be variable. All this makes it necessary to use a *doublet*, preferably consisting of lenses of the same focal power, respectively convex and concave. If these lenses are themselves weak, say one meter in focal distance, both slit images may easily be seen in the telescope and be sufficiently sharp for adjustment. If the lens first struck by light is convex and the second concave, their focal distances f_1 and f_2 respectively, and their distances apart D, the focal power of the combination used is

$$1/F = D/f_1f_2 = D/f^2 \tag{1}$$

since $f = f_1 f_2$. The position of the equivalent lens is $d = DF/f_1 = f$, and it lies on the same side of the doublet as the convex lens.

In the actual experiment, however, the rays go through the lens system twice. In this case it is perhaps best to compute the distances directly. Of the two adjustments, the one with the concave lens toward the grating and the convex lens toward the mirror has much the greater range of focus relative to the displacement D. Supposing the mirror appreciably in contact with a convex lens therefore, if b is its principal focal distance measured from the concave lens, $b + D = M$ its principal focal distance from the convex lens or mirror,

$$\frac{1}{b} = \frac{2/f_2 - 1/(f_1 + D)}{1 - D(2/f_2 - 1/(f_1 + D))} - \frac{1}{f_1} \tag{2}$$

where f_1 is the (numerical) focal distance of the concave and f_2 that of the convex lens. If we now write

$$b = B(1 - D(2/f_2 - 1/(f_1 + D) \tag{3}$$

equation (2) is easily converted into

$$\frac{1}{2B} = \frac{1}{f_2} - \frac{1}{f_1} - \frac{D}{f_1f_2} \tag{4}$$

so that the usual value of the principal focal distance has been halved relatively to the new position of the equivalent lens. If $f_1 = f_2 = f$,

$$2B = f^2/D\,;\; b = \frac{f}{2D}\,\frac{f^2 - 2D^2}{f + D}\;;\; M = b + D = \frac{f^3 + 2D^3}{2D(f+D)}$$

Thus if D increases from 2 to 25 cm., M decreases from 2450 to 165 cm., $2B$ from 2500 to 200 cm., d from 49 to 35 cm. As

b is smaller than B by equation (3), the equivalent lens is on the side of the convex lens and at a distance

$$B - M = (f^2 - 2D^2)/2(f + D)$$

behind the mirror, or

$$B - b = f(f + 2D)/2(f + D)$$

behind the concave lens.

If the system is reversed, f_1 and f_2 are to be replaced by $-f_1$ and $-f_2$ whereas D remains positive. Hence the equivalent lens has the same focal distance as before, but it is now placed in front of the system, at a greater distance than it was formerly behind it. The total displacement of the equivalent lens on reversal is about one meter.

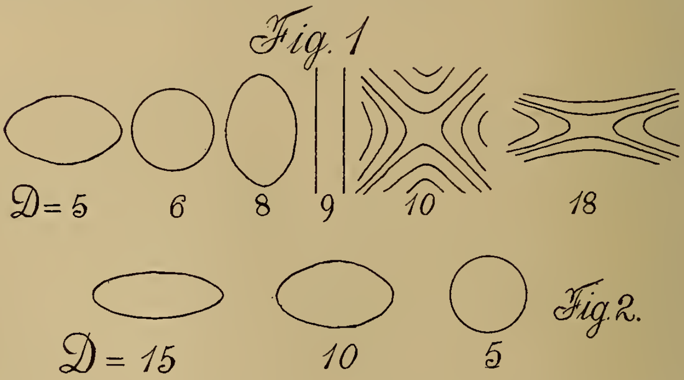
3. *The effective thickness of the lenticular compensator.*—The compensator with curved faces may change the interference pattern in two ways; viz., by changing the angle of incidence and refraction of the rays at the grating and by changing the path difference of successive rays passing through it. Both conditions are virtually the same, or at least occur simultaneously. If there is but one compensator, as above, the two effects must be small, since the rays reflected from each of the opaque mirrors, M and N, of the interferometer, must eventually enter the telescope, to unite in two nearly identical images of the slit. It was rather unexpected to observe that the interferences are still obtained, even when the two slit images are quite appreciably different in size. They are then confined to a single plane, however, as will be shown in §6.

Since the beam of light coming out of the colimator and traversing the grating is a vertical ribbon of light, several cms. high, vertically, but very thin in comparison (a few mms.) horizontally, it is relative to the vertical plane that the marked effect must be expected. If the beam consists merely of the axial pencil, the distortion of pattern due to the introduction of the doublet is slight for any value of the distance apart lenses, D. The two lenses are practically equivalent to a plate. If a broad beam is in question and the rays retrace their path, the same is still true. But if on changing D the rays do not retrace their path, so that the equivalent lens is convergent or divergent, then the rays after leaving M re-impinge on the grating at different angles than before and the interference pattern is correspondingly changed, principally in its vertical relations.

Thus it is the lens system which changes the obliquity of rays lying in a vertical plane and passing through the grating to the effect that the axial rays may represent a case of either maximum or minimum path difference. The latter will be the case when the divergent pencil which usually traverses the grating becomes convergent in consequence of a sufficiently large value of the D of the convergent lens system.

4. *Observations largely with weak lenses and short interferometer.*—The film grating used (Wallace, 14500 lines to the inch) was cemented with Canada balsam to a thick piece of plate glass, so that the total thickness of plate at the grating was $1{\cdot}734^{\text{cm}}$. This introduces a large excess of path in one of the component beams; but it is generally necessary if the stationary interferences, due to the reflection at the two faces of the plate of the grating, are to be obviated and if the ellipses produced are to be reasonably large for adjustment (cf. §6). The lens doublet was to be added on the same side as the glass specified, so that the excess of glass thickness on one side was further increased by about $\cdot 19^{\text{cm}}$ on the average. Under these circumstances the ellipses were strong, but in view of the large dispersion with inconveniently long horizontal axes.

FIGS. 1, 2.



On inserting the doublet (convex and concave lens, each 1 meter in focal distance) with its concave lens at the mirror and gradually increasing the distance D by moving the convex lens toward the grating, a series of forms were obtained which passed from the initial horizontal long ellipse, through circles, vertically long ellipses, vertical lines, into hyperbolic forms of increasing excentricity, as recorded in fig. 1.

On reversing the system, keeping the convex lens fixed near the mirror and increasing the distance D by moving the other lens toward the grating, the original ellipse usually flattened out further, as shown in fig. 2. Moving the lenses sideways, parallel to themselves, had no definite effect. Moving them fore and aft together (D constant), produced results similar to the above. The vertical lines of fig. 1 are liable to be sinuous, or to resemble the grain of wood around a knot.

If corresponding to fig. 1, the convex lens is kept fixed near the grating and the concave lens gradually moved up to it, the order of forms is reversed but not quite completely. They usually terminate in long vertical ellipses, before reaching which the wood-grained forms are sometimes passed. The same is similarly true for the case of fig. 2.

With cylindrical lenses (respectively convex and concave, each one meter in focal distance), very little effect was observed when the axes of the cylinders were parallel to the slit. With the axes perpendicular to the slit the effects of spherical lenses were virtually reproduced, except that the central fields partook of a more rectangular character.

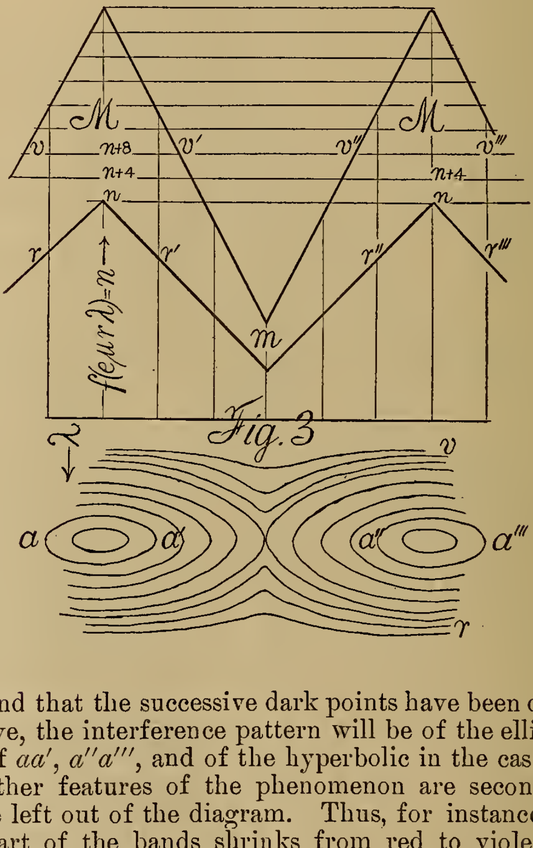
A variety of experiments were also made with strong lenses, with similar results, the interferences being seen most clearly in the principal focal plane of the telescope.

5. *Remarks.*—A few explanatory observations may here be inserted. The occurrence of the elliptic or oval and the hyperbolic type of fringes may be most easily exhibited, by laying off the order of the fringe in terms of the distance (in arbitrary units) above and below the center of the image of the slit. If we call the latter y and consider the allied colors of thin plates, for instance, $n = 2e\mu \cos r/\lambda$ or more generally $n = (e\mu/\lambda)f(y,r)$, (where e is the thickness of the plate, μ its index of refraction λ the wave length of light in case of a dark locus of the order n) is to be expressed in terms of y, r being the angle of refraction at the plate of the grating. The phenomenon will thus be coarser for red light than for violet light since μ decreases when λ increases and for the present purposes any two curves r and v, fig. 3, may be assumed as the loci of the equation in question. If now horizontal lines be drawn for $n = 1, 2, 3$, etc., they will determine the number of dark bands in the spectrum for any value of y.

If the central ray is also a line of symmetry and intersects the grating normally, it must correspond to a maximum or a minimum in n. These conditions are shown in the diagram at M, where the maximum number of points or bands occurs, and at m, where the reverse is true. The question is thus referred to two sets of loci rr' and vv', or $r'r''$ and $v'v''$, etc. In the former case $e \cos r$ varies with y in the same sense as μ/λ; in the latter in the opposite sense and is preponderating in amount. Both may vary at the same rates in the transitional case, in which therefore the two curves r and v are at the same distance apart for all values of y.

Suppose furthermore the same phenomenon is exhibited in terms of wave length λ, as in the lower part of the diagram, the spectrum being equally wide for all values of y, while at any given y, the upper diagram still shows the number of dark points or bands between r and v. If now we suppose that under any conditions these dark points are grouped symmetrically with reference to any given color (which is probable, for a maximum or a minimum of any value of y will be so for all values) and that the successive dark points have been connected by a curve, the interference pattern will be of the elliptic type in case of aa', $a''a'''$, and of the hyperbolic in the case of $a'a''$.

FIG. 3.



The other features of the phenomenon are secondary and therefore left out of the diagram. Thus, for instance, the distance apart of the bands shrinks from red to violet and the ovals, etc., are only appreciably symmetric because they occupy so small a part of the spectrum. Whether the long axes of the ellipses are horizontal or vertical depends upon the slope of the lines r and v. Maxima and minima will not, as a rule, occur close together, though in certain wood-grain shaped patterns this seems to be the case.

In conclusion, therefore, the main feature in modifying the type of interference pattern is the varying thickness of the compensator. For oval types the preponderating lens is convex, for the hyperbolic type it is concave. Neither of these lenses are here appreciably affected in modifying the horizontal distribution of path difference because the dispersion of the grating requires a horizontally parallel system of rays.

6. *Telescopic interferences.*—If interference patterns of small angular extent are to be obtained, it is essential that the rate at which obliquity increases from ray to ray be made as large as practicable. Probably, therefore, an opportunity for realizing these conditions may be found within the telescope, i. e. after the rays pass the objective. The endeavor would, therefore, be directed to bringing two spectra, focussed in two planes one of which is behind the other and consequently of different sizes, both vertically and horizontally, to eventual interference.

The experiment was made on the long interferometer, fig. 4, the distances between mirror M and grating G and from the latter to the mirror N being nearly two meters each. L is the lenticular compensator, consisting of two lenses, respectively concave and convex, each having the same focal distance $f = \pm 50^{\mathrm{cm}}$. The distances apart, D, of the lenses may be varied. The glass plate C', which is revolvable about the vertical, is thick enough to exactly counterbalance, if necessary, the thickness of the glass plate of the grating and of the lens system L. A sharp wedge sliding transversely may also be used. It is best to replace C' by two plates of glass, one thick and the other thin, so that the latter may be removed.

The telescope directed along the axis R will, therefore, in general see two white slit images, A and A', fig. 5, not both in focus at once; A coming from M being larger, A' from N (parallel rays) smaller. The focal plane of A' will be towards the grating as compared with A and A' is larger than A, in proportion as the distance apart of the lenses, L, is larger. Similarly the two spectra are observed along the axis, D, not in focus at once and of different areas.

To obtain the interferences, the slit image A must be placed anywhere within A' and they will occur at the top of the spectrum if a and a' are vertically in coincidence; in the middle if b and b' coincide; etc.

The plane of the new interferences is no longer the principal focal plane, containing the Fraunhofer lines, but lies in front of it; i. e. towards the eye of the observer and away from the grating. This distance, measured along D for the given small telescope used, was fully 1^{cm}. The focal planes of the two spectra are usually not so far apart. A' corresponds to a virtual object behind the observer.

If the vertical plane at which the interferences lie be taken as the image, the object would be situated about 3 meters beyond the objective of the telescope used. This would place it about 30$^{\text{cm}}$ in front of the mirror M or N, where there is but

FIGS. 4–7.

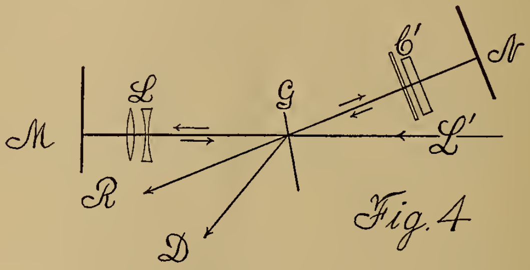


Fig. 4

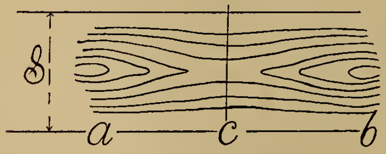


Fig. 7.

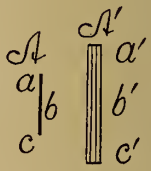


Fig. 5.

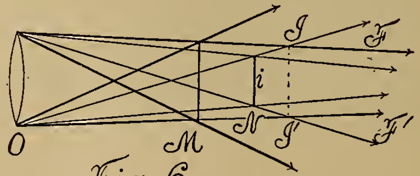


Fig. 6.

a single beam in each case. In fact, the telescope may be brought quite up to the grating. Hence interference is produced in the telescope itself, where rays are relatively very divergent, a condition which accounts for the smallness of the interference pattern. This understanding of the case is tentatively shown in fig. 6, where O is the objective of the telescope, M the larger image from the mirror with the lens compensator and N the image from the other mirror (parallel rays). If the corresponding rays be drawn through the extremity of M and N, their fields of interference F and F' would begin in the plane II'. For axial rays it would be at i. Thus the locus as a whole would not be a plane, and this seems to be the case. If the telescope moves towards the grating, II' moves toward the right in the figure, as though the virtual object beyond the grating were fixed in position. At all events, the problem is to find the interference diagram of two symmetrical, plane, parallel spectra of different areas and placed at definite distance apart.

The appearance of the fringes is indicated in fig. 7 where S is the height of the spectrum, usually quite out of focus. There are many more lines than could be drawn in the sketch. The ends a and b seem to surround small ellipses, but these are not quite closed on the outer edge. The center of symmetry is at c. The demarcations are stronger and broader vertically, if the distance apart of the doublet L, fig. 4, is small; fainter but nevertheless clear and narrower if this distance is large. Horizontally the fine lines thread the spectrum. The best results were obtained when the lenses L are less than 1^{cm} apart, the middle band being about half as high as the spectrum. Two contiguous lenses gave a design which nearly filled the spectrum. For practical purposes the lens compensator L is to be attached to the mirror, M, just in front of and moving with it. It makes little difference, here, whether the concave lens or the convex lens of the doublet L is foremost.

If the micrometer M is moved, or if the telescope is slid to the right or left, or forward, so as to take in other parts of the spectrum, the nearly closed lines at a and b become finer and finer crescent shaped lines, always open outward, till they pass beyond the range of vision. The whole phenomenon remains on the same level of the spectrum. On moving the telescope towards G, fig. 4, the ocular has to be drawn outward (towards the eye) till it is fully 2^{cm} beyond the position of the principal focal plane. The whole spectrum is now seen with the interferences from red to violet (no ellipses), but having the same relative position as before. The central horizontal band measures about 1/5 the height of the spectrum, while the fine parallel horizontal lines extend to the upper and lower edges. The appearance is now curiously like a blunt wedge; the band is nearest the eye and the lines running abreast extend towards the rear. This impression is probably an illusion due to the shading. The lines grow finer and are more crowded toward the bottom and top of the spectrum. The illusion of a reëntrant wedge is thus not possible.

To use this interference pattern for measurement, the cross hair is supposed to pass through the region c, fig. 7, symmetrically. Very slight motion of the micrometer mirror *M* then throws *c* either to the right or the left of the cross hair. In this case the lens doublet at *L* is attached to the mirror and moves with it, as stated. To obtain the extreme of sensitiveness, the path difference of *NG* and *GM* must be all but zero; i. e. the grating plate *G* and the lens doublet *L*, fig. 4, must be all but compensated for equal air distances, by the compensator *C'*. In this case of full compensation the interferometer pattern in the absence of a doublet *L*, would be enormous and diffuse, seen preferably in the principal plane of the telescope, but useless for adjustment. The introduction of a lenticular compensator balanced by a compensator in *GN*, transforms the huge pattern into the small interference fringes in question, with the advantage that the high mobility of the course design has been retained. In other words, an index suitable for measurements has been found, compatible with extreme sensitiveness. In fact, it is difficult to place the micrometer mirror *M* so that the region *c*, fig. 7, is exactly bisected. As the plane in which these interferences are seen most distinctly is 1^{cm} or more anterior to the principal focal plane, the Fraunhofer lines are unfortunately blurred and a cross hair is needed as a line of reference.

Brown University, Providence, R. I., July, 1915.

Art. XXIV.—*Radioactivity of Spring Water;* by R. R. Ramsey.

The springs tested are flowing springs which issue from the ground at the base of or on the side of a hill. A great number are those which were used by the early settlers as a source of water supply. Some are still the main water supply of the farm. Most of these springs are the so-called "never-failing" springs which flow the entire year. All are more or less affected by the rainfall.

The wells are dug, driven, or drilled wells whose depth varies from 15 feet to 150 feet. Pumps must be used to raise the water to the surface of the ground.

The method of measurement is the "shaking method" as used by Schmidt* in which a known volume of water is shaken vigorously with a known volume of air for two minutes, and then the air is pumped through the chamber of the electroscope by means of a rubber bulb pump until the emanation is thoroughly mixed with the air in the electroscope and the air in the shaking can. Then the following equation holds:

$$E = \frac{1}{V_1}\left(\frac{V_2 + aV_1}{V_2}\right)\left(\frac{V_2 + V_3 + V_4}{V_4}\right) e$$

Where, V_1 = the volume of water in the shaking can.
V_2 = " " " air " " " "
V_3 = " " " " " " bulb pump and connecting tubes.
V_4 = " " " " " " ionization chamber.
a = the absorption coefficient of water for radium emanation.
e = the amount of emanation per liter in V_4, the electroscope.
E = the amount of emanation per unit of volume of water.

Electroscope.—The electroscope used at first was one made in the shop of sheet tin. Sulphur was used as an insulator. Later a Schmidt electroscope made by Spindler and Hoyer, Gottingen, was used. Both electroscopes were calibrated by using Duane and Laborde's formula,†

$$e = \frac{i_{\max}}{6{\cdot}31 \times 10^6\,(1 - 0{\cdot}572\ S/V)}\ \text{curies}$$

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* Phys. Zeitschr, vol. vi, p. 561, 1905.

† Le Radium, vol. xi, p. 5, 1914; Ann. der Phys., vol. xxxviii, p. 959, 1912; Compt. Rendus, vol. cl, p. 1421, 1910; Jour. de Phys., vol. iv, p. 605, 1905.

Where e = amount of emanation in electroscope.
i_{max} = maximum current, at end of three hours, in E. S. units.
V = volume of ionization chamber.
S = surface of ionization chamber.

This formula applies to a cylindrical chamber whose volume is about one liter and whose height is one to three times the diameter.

Accuracy of the formulæ.—As a test of the Duane formula the following test made by two students will serve. The two electroscopes were connected together and filled with emanation, care being taken to see that the emanation was the same density in each electroscope. This experiment was carried out under favorable conditions in the laboratory.

Electroscope	"Tin"	Schmidt
Observer	F. G. T.	W. D. S.
Diameter of chamber	10·8	7·8 cm.
Height of chamber	12·1	20·3 cm.
Volume of chamber	1102·	968· cu. cm.
Surface of chamber	594·	586·6 sq. cm.
Capacity of electroscope	17·	6·3 cm.
Amount of emanation	206000· × 10^{-12}	200000· × 10^{-12} curies

Another test made in the field at the spring by the same observers will give an idea of the accuracy under unfavorable conditions.

Illinois Central Spring, July 24th, 2 p. m.

Water temperature, 12°·4 C.	Air, hot and windy.	Temperature 104° F. in shade.
Observer	F. G. T.	W. D. S.
Electroscope	"Tin"	Schmidt.
Curies per liter of water	360· × 10^{-12}	300· × 10^{-12}

The following test made at a spring will give an idea of the accuracy of Schmidt's shaking method. The same electroscope was used, but three different shaking cans were used.

J. C. S. Spring, Aug. 5th, 1914.

Water temperature, 12°·5 C. Air temperature, 30° C.

	I	II	III
Time of beginning	11·03 A.M.	11·46 A.M.	2·00 P.M.
Vol. of water	·707	3·000	5·000 liters.
Vol. of air	·943	4·100	2·100 liters.
Mean deflection of electroscope per minute	16·	29·5	52·5 divisions.
Curies per liter	425· × 10^{-12}	435· × 10^{-12}	443· × 10^{-12}

These observations were taken every minute and the mean deflection from 15 minutes to 20 minutes from the time of putting in the emanation was used. By referring to an experimental curve the maximum deflection per minute or the deflection at the end of three hours was calculated. Corrections were made for the natural leak and the amount of radium C, from the former experiments.

The method has an accuracy of 5 per cent or 10 per cent as carried out at the spring using 15 or 20 minute readings. When carried out in the laboratory using three hour readings the accuracy is 2 per cent to 5 per cent.

During March of this year the electroscopes were calibrated by using Emanation standard E54, and were found at room temperature, 20°, to agree with Duane and Laborde's formula as given above to within 9 per cent. Emanation standard E54 is certified by the Bureau of Standards to be accurate to within 3 per cent.

If instead of using $6{\cdot}31 \times 10^6$ as the value of the current in electrostatic units which is given by one curie radium emanation when in equilibrium with its products, one uses $6{\cdot}02 \times 10^6$ as is done by A. Gockel,* the agreement is within 4 per cent. Using the corrections for temperature and pressure as given by the same author in the following formula:

$$I = I_{\text{obs.}}\,(0{\cdot}0007(760{\cdot} - p) + 0{\cdot}002(t - 15°))$$

the agreement is within 3 per cent.

Thus the Duane and Laborde formula under the above conditions gives accurate results.

The observations given below were for the most part made at the springs within a half hour after taking the water from the spring. The method of making the observation was as follows: The shaking can is rinsed out and then filled by immersing the can, if possible, and letting the water run in with as little agitation as possible. When full the can is closed, set level and then two stopcocks are opened, one at the top to admit air and another on the side to allow the water to flow out. When the water has quit flowing the stopcocks are closed. By previous experiment the amount of water under these conditions is known. The water and air is then shaken vigorously for two minutes and then the air is pumped through the electroscope until the emanation is equally distributed throughout the air in the can and the electroscope.

Readings are then taken on the leaf of the electroscope at regular intervals for 15 or 20 minutes. Then the emanation is pumped out. The observations taken at various times during

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* Die Radioaktivität von Boden und Quellen, p. 102.

the past year are given in table form. The location as given in the table is taken from the topographic maps of the U. S. Geological Survey.

City Water

Location	Date	Temp.	Curies per liter
Bloomington, Ind.	Feb. 24, 1914	5·° C.	27· $\times 10^{-12}$
Indiana University	Mar. 2,	5·	45·
Oxford, Ohio	Aug. 12,	19·	70·
Union City, Ind.	Aug. 18,	19·	45·
Celina, Ohio	Aug. 20,	26·	70·

Latitude	Longitude	Date	Temp.	Curies per liter
		Ohio Wells		
39–35·8 N.	84–44·2 W.	Aug. 15, 1914	15·°	95·
39–36·9	84–44·5	Aug. 27,	--	70·
39–35·	84–43·1	Sept. 2,	13·	200·
40– 9·	84–43·6	Aug. 12,	12·	185·
		Ohio Springs		
39–35·7	84–44·1	Aug. 24,	--	420·
39–35·	84–43·1	Sept. 2,	16·	560·
39–35·7	84–45·	Sept. 7,	--	100·
39–36·2	84–46·	Sept. 7,	15·8	250·
39–36·1	84–46·1	Sept. 7,	19·5	300·
39–36·	84–45·8	Sept. 7,	17·	610·
39–35·3	84–46·3	Sept. 7,	19·5	140·
39–34·7	84–48·5	Sept. 7,	17·	350·
39–34·8	84–48·5	Sept. 7,	17·	350·
		Indiana Springs		
39–10·1	86–33·2	Mar. 4,	12·5	600·
39– 7·	86–15·	Mar. 6,	16·	355·
39– 8·8	86–30·1	Mar. 13,	10·3	430·
39– 8·8	86–30·1	May 16,	11·5	170·
39– 8·6	86–30·	Mar. 14,	11·5	660·
39–10·1	86–33·2	May 23,	12·2	265·
39– 9·4	86–34·3	May 23,	11·	77·
39– 8·4	86–34·5	May 23,	12·3	175·
39–10·6	86–32·3	Sept. 24,	13·	650·
39–10·6	86–32·2	Apr. 15, 1915	12·	1150·
39– 9·9	86–31·	May 10,	--	425·
39–10·2	86–30·7	May 10,	12·5	2150·
39–10·11	86–31·	May 26,	--	500·
39–10·2	86–33·1	May 27,	12·	750·
39–10·2	86–32·	June 3,	--	1640·
39– 9·9	86–31·6	June 3,	--	1920·

INDIANA SPRINGS.

39– 9·1	86–30·3	June 4,	11·8	1260·	$\times 10^{-12}$
39– 9·	86–30·3	June 4,	11·4	1310·	
39– 8·5	86–30·4	June 4,	12·	725·	
39– 8·4	86–30·4	June 4,	12·	510·	
39– 8·5	86–29·7	June 4,	--	790·	
39– 8·6	86–29·6	June 4,	13·	540·	
39– 8·6	86–29·9	June 4,	--	570·	
39– 8·85	86–30·15	June 4,	12·	700·	
39– 9·45	86–31·1	June 4,	--	700·	
39– 9·4	86–31·1	June 4,	13·	535·	
39–10·1	86–33·2	June 10,	12·	355·	
39–10·6	36–32·3	June 10,	11·8	1120·	

In a few cases the spring has been measured two or more times, the result being different each time. The emanation content of the springs varies with the flow. Some of the higher values are obtained from "wet weather" springs, the measurement being made during a wet period.

Dept. of Physics, Indiana University,
June 19, 1915.

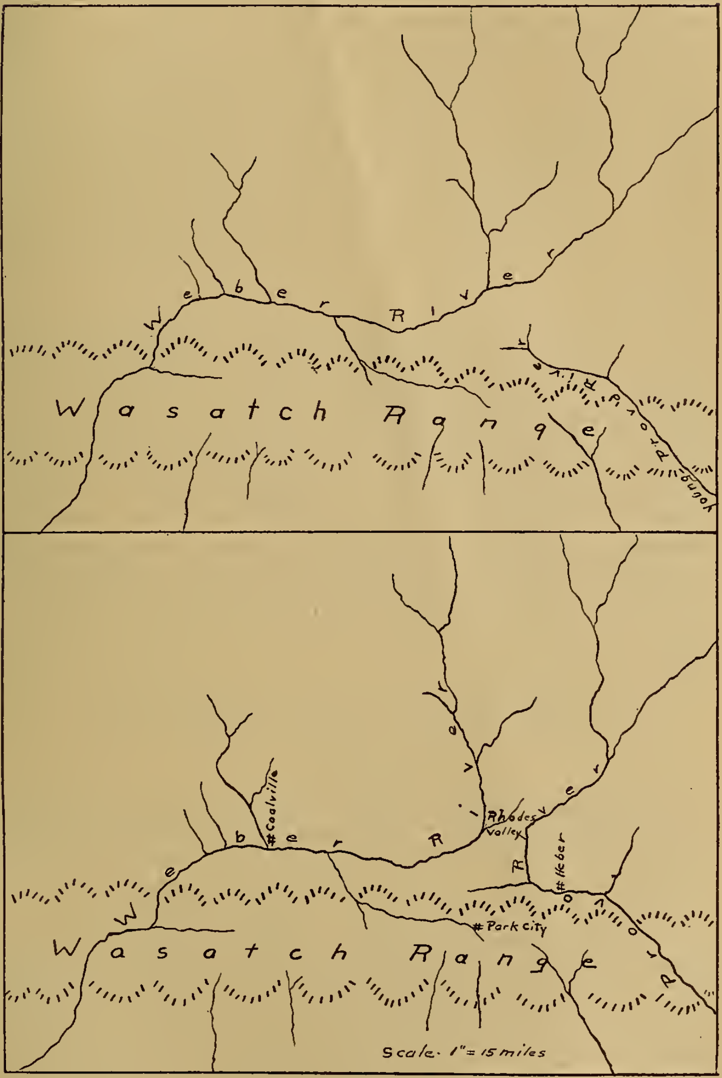
ART. XXV.—*Stream Piracy of the Provo and Weber Rivers, Utah*; by G. E. ANDERSON.

THE Provo River is one of a series of streams which have cut deep canyons into the Wasatch Range and drain westerly into the Great Basin. Of these may be mentioned the Ogden, Weber, Little and Big Cottonwood, the American Fork, the Provo and the Spanish Fork all having steep gradients and picturesque canyons. Two of these, the Weber and the Provo, have cut entirely through the Range and have contiguous drainage basins east of the Wasatch and now their head waters drain the west end of the Uinta Range. The Weber was the first to cut through the Range and is the master stream of the whole system. It had in fact developed the whole drainage basin east of the Wasatch before the Provo had cut through that range and the head waters of the present Provo as far down as Rhodes Valley was then a south fork of the Weber—the two forks of the Weber uniting at what is now the village of Peoa.

Between Peoa and Rockport the Weber River erodes its channel in the resistant and nearly vertically dipping partly metamorphosed sandstones and conglomerates of Triassic age with the direction of the river channel at right angle to the strike of the sandstones, causing channel erosion over them to be very slow and the gradient of the Weber thereby held up at this point until the south fork of the Weber became a somewhat mature river valley immediately above its junction with the north fork, with a sluggish and meandering stream, which widened its valley to a width of two and one-half miles and for a distance of eight miles up stream to the south. This valley is the present Rhodes Valley. It has a gradual northward slope from an elevation of 6500′ in the south end to 6300′ at the north end of the valley. A slight amount of aggradation has taken place in the valley by the small streams draining the hills from the east and west sides. This, however, has not materially changed the gradient or filled up sufficiently to cause any well-defined erosion through the valley since it was formed by the south fork of the Weber.

While Rhodes Valley was being formed the Provo was cutting down its barrier—the Wasatch Range. Channel erosion through the Wasatch was slow, however, so that the head waters of the Provo on the east side had time to widen out the valley in which the town of Heber is now located. Seven miles above Heber, at Hailstone, the Provo head erosion divided into two tributaries, one reaching out in a northerly

FIGS. 1 AND 2.


Weber River
Wasatch Range
Provo River
Coalville
Rhodes Valley
Heber
Park City
Scale. 1" = 15 miles

direction and here draining the east side of the Wasatch up to Park City made the Ontario Drainage Tunnel of that mining camp a possibility. The other tributary reached out easterly and cut a narrow valley almost due east a distance of six miles where it tapped the ancient south Fork of the Weber at the south end of Rhodes Valley. The erosion bed of this tributary of the Provo was about two hundred feet lower (6300 elevation) than the floor of Rhodes Valley (6500 feet) at the point where the small branch of the Provo tapped the considerably larger stream of the South Fork of the Weber. The sudden increase in gradient of the South Fork of the Weber on being tapped caused it to rapidly entrench its channel, forming a gorge in its former valley which has extended up stream about eight miles, or to about three miles east of Woodland.

It is evident that by tapping the South Branch of the Weber at this point the Provo acquired about one-half of the head waters of the Weber—as both forks of the Weber had approximately the same drainage basins and the flow of the Provo was thereby practically doubled. This case of stream piracy is of very recent date as the entrenching of the stolen south fork of the Weber is still going on.

Fig. 1 is a sketch map of the Coalville, Utah, quadrangle showing the probable relations of the Weber and Provo River Basins before the capture. Fig. 2 shows the relations of the same River Basins as they are at present, after the capture.

SCIENTIFIC INTELLIGENCE.

I. Geology.

1. *Geological Survey of West Australia.*—The activities of the West Australian Survey as described in the Annual Progress Report for 1913 (29 pp., 2 maps) cover a wide field with special attention to economic features. "Standard" maps on a scale of 4 miles to the inch and "District" maps on various scales are now available for approximately one-half of the country. In addition to these, 93 maps of "individual" centers have been published. The area of unexplored country is large and numerous mining centers are active; the time of the survey staff is therefore about equally divided between reconnaissance and detailed field and office studies. Preliminary papers on areas of economic importance by H. P. Woodward, T. Blatchford, J. T. Jutson, H. W. B. Talbot, E. deC. Clarke, F. R. Feldtmann, and C. S. Honman, are included in the Progress Report for 1913.

Among the interesting results of the year's work is the discovery of Cretaceous fossils in the Gingin "chalk," types like the sponge

(*Peronella*), the coral (*Coelosimlia*) and the brachiopods *Trigonesmus* and *Magas*, new to Australia but common to the old world, indicating a homotaxial relation with the Indian system.

The Geology of the Country between Kalgoorlie and Coolgardie, by C. S. Honman (Bulletin 56, 80 pp., 31 figs., 2 maps, 1914), deals with an interesting series of Pre-Cambrian rocks, including a stratum of crushed conglomerate.

A Geological Reconnaissance of a portion of the Murchison Gold Field, by H. P. Woodward (Bulletin 57, 103 pp., 50 figs., 5 plates, 1914), contains a description of the physiographic features and a brief account of the Weld range with its remarkable deposits of almost pure hematite estimated at "26 to 27 million tons," at present valueless because of its inaccessibility and its distance from coal fields.

Miscellaneous Reports (Bulletin 59, 252 pp., 50 figs., 23 plates, 1914) embraces 18 short papers on economic subjects by members of the Survey staff. H. E. G.

2. *Physiographic Geology of West Australia*, by J. T. JUTSON (Western Australia Geological Survey, Bulletin 61, 1914, 229 pp., 119 figs., 3 plates).—Chapters embodied in economic reports of the West Australia Survey during past years have served to call attention to the extremely interesting physiographic features of that state and to create the desire of the reader for a systematic account of the western half of the continent along the lines of Griffith Taylor's admirable work on "The Salient Features in the Physiography of Eastern Australia." Topographic maps are lacking and portions of the state remain unexplored, and Mr. Jutson's report is therefore properly described as "An Outline." The plan adopted is, however, well chosen and the literature intelligently used, with the result that a book of high educational value has been produced. A foreigner interested in Western Australia would naturally begin his studies with this bulletin. The character of the book is indicated by the following partial list of contents: Rainfall and Vegetation, Outline of Geology, Physiographic Divisions, The Great Plateau, Drainage Systems and their Development, Origin and Growth of Salt and Dry Lakes, Mountains, Sunk Lands, Coastal Plain, Rock Weathering.

H. E. G.

II. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *The Social Problem: A Constructive Analysis;* by CHARLES A. ELLWOOD. Pp. xii, 255. New York, 1915 (The Macmillan Company).—Professor Ellwood's writings are always characterized by a breadth of vision coupled with a profound distrust of any single principle of human life or any all-inclusive formula for explaining society. In the book in hand he undertakes to analyze the social problem, by which he means the problem of "human living together." He deprecates the attention commonly devoted to "social problems" as disconnected and unrelated phenomena, capable of solution separately. The

actions and interactions which make up life in society are so complex and interrelated that only by grasping the root principles which govern the control of all human relations can the social problem be solved. The preservation and progress of civilization demand a wise and harmonious valuation by all the members of society of the ideas and ideals which constitute both our social heritage from the past and our goal of endeavor for the future. It is necessary to select ideas and ideals for eliminination or perpetuation, to get all the members of society to agree on a program of conservation for the approved ideas and ideals, and then to devise means to put this program into practical effect. The various elements in the problem are analyzed, and individualistic capitalism and materialism are found to lie at the bottom of much of the social chaos. A revaluation of family life, of government, of religion, of morality is called for if Western civilization is to survive. This can not be accomplished by revolutionary or one-sided methods, but by a gradual process of education, particularly of the young, in right ideas of social relations. The need of the hour is for scientifically trained social leaders.

2. *Societal Evolution; A study of the Evolutionary Basis of the Science of Society.* By ALBERT GALLOWAY KELLER. Pp. xi, 338. New York, 1915 (The Macmillan Company).—In this book Professor Keller raises the question whether the formula of Darwinian evolution is applicable to the development of human society in anything more than a vague and analogical sense. He answers this question in the affirmative, and proceeds to justify his answer. Recognizing that the human type of evolution is now mental and societal, instead of individual and physical as with the lower animals, the author takes up in turn each of the four elements of Darwinian evolution—variation, selection, transmission, and adaptation—and shows how each exists in human society and each plays a rôle in societal evolution essentially identical with that which it performs in the sort of evolution dealt with by Darwin. Thus the social scientists are afforded a rational justification for using this valuable and illuminating formula freely and with confidence in their own special field. The study is built upon Professor Sumner's well-known conception of the mores, and the influence of Sumner is clearly manifest and frankly acknowledged throughout, although the author's conclusion is different from that reached by Sumner.

3. *British Association for the Advancement of Science.*—The annual meeting of the British Association will be held at Manchester from Sept. 7 to 11: Professor Arthur Schuster is the president.

4. *American Association for the Advancement of Science.*—The Pacific Coast Meeting of the American Association was held in San Francisco during the week of August 2d. Numerous affiliated societies had sessions at the same time.

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[FOURTH SERIES.]

Art. XXVI.—*The Mammals and Horned Dinosaurs of the Lance Formation of Niobrara County, Wyoming;* by Richard Swann Lull.

[Contributions from the James Dwight Dana Memorial Fund, Yale University.]

Introduction

Ever since the completion of the Ceratopsia monograph in 1905, the writer has desired to visit the famous region which produced so many of the remarkable creatures which form the subject-matter of that volume. Last summer, through the kind coöperation of my colleague, Professor Schuchert, an expedition to Nebraska was made possible, and when a visit to the "Ceratops beds" of Wyoming was also planned, Mr. Schuchert immediately suggested that a reconnaissance be made with the particular purpose of determining, if possible, the stratigraphic sequence of the mammal-bearing beds. To this end the Faculty of the Geological Department of Yale voted a sum of money from the research fund which the family of Professor James Dwight Dana have dedicated to his memory. The brief visit, while not in itself productive of many facts, nevertheless rendered possible a visualizing and better appreciation of the work already done on the area and stimulated the following compilation and summary of our knowledge of the Cretaceous mammals.

The sources of information are the large collections made principally by J. B. Hatcher, aided by Professor C. E. Beecher, Mr. O. A. Peterson, and others, together with the field notes and correspondence of the two first mentioned. There were also available the writings of Professor Marsh descriptive of the mammals themselves, and the subsequent work of Messrs. Hatcher, Stanton and other authorities mentioned in the bibliography.

I am indebted to Mr. O. A. Peterson of the Carnegie Museum in Pittsburgh for aid in the compilation of localities, as well as to Messrs. Gidley and Gilmore of the United States National Museum; and especially to Mr. J. T. Doneghy, Jr., graduate student in paleontology at Yale, who shared the field trip and prepared the geologic section of the Niobrara County beds. Professor Schuchert's kindly criticism and generous aid add to the already large sum of my debt of gratitude to him.

The Problem

The late Cretaceous beds of Wyoming, which have received from the United States Geological Survey the official designation of Lance formation, have borne at various times the names of Laramie formation, Converse County beds, and Ceratops beds, all of which are open to criticism on one ground or another. The strata are notable for having produced a large number of most characteristic fossils, the skulls of horned dinosaurs, in addition to other reptilian remains, but also for having proved in certain localities a veritable mine of treasure by the production of thousands of teeth and bones of the tiny contemporaneous mammals.

Whether such contemporaneity was exact, or whether the mammals differed from the associated dinosaurs in level, facies and implied habitat, and whether they occurred at more than one level were aspects of my problem. If the latter proved true, it would be interesting to learn whether or no a faunal sequence exists in the mammals comparable to that which the ceratopsian skulls seem to show, and what is the relationship of the mammals to older and newer mammalian faunas. It was hoped that more perfect, possibly associated skeletal material might be found, but success in this regard is still short of fulfillment.

Historical Résumé

To John Bell Hatcher belongs the honor of discovering, not only the rich mammalian locality under discussion, but, with the exception of a premolar tooth, an imperfect molar and the distal end of a humerus found by Dr. J. S. Wortmann in Dakota and described by Cope in 1882 as *Meniscoëssus conquistus*, the Cretaceous mammals themselves. In 1888, Mr. Hatcher, then an aid to Professor Marsh, searched for mammals in the so-called Laramie formation in Montana and South Dakota, but without success. The following year, however, he went into what was then Converse County, Wyoming, in pursuit of horned dinosaurs, the discovery of which had been made known to him the year previous, and the results of the next few years (1889–1892) not only brought to light the remarkable series of more than thirty skulls and skeletons of these and other dinosaurs, but several thousand isolated teeth, jaws, and bones of mammals. To Hatcher, therefore, belongs the major credit for the discovery of this material, but he was ably seconded by Messrs. Peterson, Utterback, and Sullins. Peterson's work was especially valuable if one may judge from the field and museum records, for "Peterson's Quarry" is one of the most productive localities of all.

Although Hatcher does not mention it, Professor Charles E. Beecher of Yale was a member of Hatcher's party during the summer of 1889 and the following spring (1890) and did a large part of the actual work on the mammals.

Hatcher (1896, p. 119) thus describes the method of field research:

> "The small mammals are pretty generally distributed but are never abundant, and on account of their small size are seen with difficulty. They will be most frequently found in what are locally known as 'blow outs' and are almost always associated with garpike scales and teeth, and teeth and bones of other fish, crocodiles, lizards and small dinosaurs. These remains are frequently so abundant in 'blow outs' as to easily attract attention, and when such a place is found careful search will almost always be rewarded by the discovery of a few jaws and teeth of mammals. In such places the ant hills, which in this region are quite numerous, should be carefully inspected as they will almost always yield a goodly number of mammal teeth. It is well to . . . . sift the sand contained in these ant hills, thus freeing it of the finer materials and subjecting the coarser material remaining in the sieve to a thorough inspection for mammals. By this method the writer has frequently secured from 200 to 300 teeth and jaws from one ant hill. In localities where these ants have not yet

established themselves, but where mammals are found to be fairly abundant, it is well to bring a few shovels full of sand with ants from other ant hills which are sure to be found in the vicinity, and plant them on the mammal locality. They will at once establish new colonies, and, if visited in succeeding years, will be found to have done efficient service in collecting mammal teeth and other small fossils, together with small gravels, all used in the construction of their future homes."

Thus it was that the bulk of the Yale collection was secured. At first the collecting seems to have been done somewhat at random, or at any rate no record of exact locality is noted with the various specimens. Later, however, each specimen bore a quarry number, so that not only can its exact geographical origin be determined, but the stratigraphic level may also be learned with a considerable degree of accuracy.

This material speedily began to find its way to New Haven, especially while Beecher was in the party, as Professor Marsh's comments show, and with his characteristic energy when once his interest was aroused, the latter at once began the publication of the descriptions and figures of these remarkable forms.

Descriptions by Professor Marsh

The first of these descriptive papers appeared in this Journal for July, 1889, in which he described seventeen species representing no fewer than twelve distinct genera. August of the same year saw the publication of the second part of the paper, and the third appeared in March, 1892, bringing the total number of species up to thirty-two, while of genera there were eighteen in all. These publications also include a discussion of relationships and family definitions and were but the projected beginning of an extensive monograph upon the group, the completion of which was prevented by the distinguished author's untimely death. Aside from a quarto publication by Professor Osborn, reprinted in part in his "Evolution of mammalian molar teeth," little has been done on the Lance mammals by other writers, and practically every genus and species known is contained in the original series described by Professor Marsh and based upon types preserved in the Yale collection.

Summary of the Lance fauna

The Lance formation has produced an extensive vertebrate fauna of which the dinosaurian element is by far the most conspicuous, consisting as it does of the terminal representatives of all the phyla except the long extinct Sauropoda. There were also turtles and crocodiles, lacertilians and champsosaurs, and a number of genera and species of tiny mammals.

The mammalian forms are included under at least two of the Mesozoic orders, Multituberculata and Trituberculata, the first of which is to be included under the infraclass Didelphia or marsupials, while of the Trituberculata Matthew says some are demonstrably marsupial, others of uncertain relationship, none demonstrably placental (1914, p. 386).

The list of genera and species thus far described from the Lance follows (Hay 1902, pp. 564 *ff.*):

ORDER MARSUPIALIA

SUBORDER POLYPROTODONTIA

(TRITUBERCULATA)

Family Stagodontidæ Marsh

Stagodon nitor Marsh
" *tumidus* Marsh
" *validus* Marsh
Thlœodon padanicus Cope
Platacodon nanus Marsh

Family Cimolestidæ Marsh

Pediomys elegans Marsh
Batodon tenuis Marsh
Didelphodon comptus Marsh
" *ferox* Marsh
" *vorax* Marsh
Cimolestes curtus Marsh
" *incisus* Marsh
Telacodon lævis Marsh
" *præstans* Marsh

Family Dryolestidæ Marsh

Dryolestes tenax Marsh

SUBORDER ALLOTHERIA (MULTITUBERCULATA)

Family Bolodontidæ Osborn

Allacodon fortis Marsh
" *lentus* Marsh
" *pumilis* Marsh
" *rarus* Marsh

Family Plagiaulacidæ Gill

Cimolomys agilis (Marsh)
" *bellus* Marsh
" *digona* Marsh
" (*Halodon*) *formosus* (Marsh)*
" *gracilis* Marsh
" (*Nanomyops*) *minutus* (Marsh)*

---

* Referred to *Ptilodus* by Gidley, 1909, pp. 622–623.

Cimolomys nitidus (Marsh)
“ *parvus* (Marsh)
“ (*Halodon*) *serratus* (Marsh)
Meniscoëssus (*Selanacodon*) *brevis* (Marsh)
“ (*Tripriodon*) *caperatus* (Marsh)
“ “ *cœlatus* (Marsh)
“ *conquistus* Cope
“ (*Selenacodon*) *fragilis* (Marsh)
“ (*Dipriodon*) *lunatus* (Marsh)
“ “ *robustus* (Marsh)
“ (*Halodon*) *sculptus* (Marsh)
Oracodon anceps Marsh
“ *conulus* Marsh
Camptomus amplus Marsh

On comparison with older faunæ, no genera in common between the Lance and the Triassic, Jurassic or Comanchian (Morrison) are found, with the doubtful exception of *Dryolestes*, of which there are several species in the latter beds and but one in the former; as the Lance species, however, is based upon an imperfect jaw without teeth, its inclusion in the genus is open to question.

Comparison with the Belly River fauna.—Of the few forms reported from the Belly River, one is referred to the genus *Ptilodus* (*P. primævus* Lambe). Of this species Hatcher says it is related to but somewhat more primitive than *Meniscoëssus conquistus* Cope from the Laramie of South Dakota. The only other species which I find recorded is *Boreodon matutinus* Lambe, related, according to Hatcher, to *Stagodon*.

Comparison with the Paskapoo fauna.—Barnum Brown (1914A, p. 361) thus speaks of the mammals from the Paskapoo formation of Alberta:

> “Near Erickson's Landing, about 20 miles below the town of Red Deer, there is an enormous slide, the largest seen along the [Red Deer] river, where a full section of the canyon wall 100 yards in length has slipped down to the river level. In this fallen material there are many blocks of sandstone carrying on the lower side clay pebbles, *Unios*, and a few jaws, teeth, and bones of mammals, identified as follows:

“MULTITUBERCULATA:	TRITUBERCULATA:	
Meniscoëssus sp. indesc.	*Didelphops* sp.	? Marsupiala
Ptilodus sp.	? *Batodon* sp.	
Cimolodon sp.	? *Thlæodon* sp.	
	? Gen. indesc.	? Insectivora
	? Gen. indesc.	
	Pantolestidæ gen. indet.	
	? Creodonta	
	? Taligrada”	

Of these Brown says the multituberculates and trituberculates "are unmistakably those of the Lance, but the placental mammals have not been found in the Lance and appear to belong to the Palæocene groups of mammals, although they do not compare closely with Puerco or Torrejon genera. This layer was located in the bluff at a point 150 feet above the river. Apparently it was a local deposit, an old river channel of the Paskapoo period which crossed the present river at right angles. Twenty-five feet above the mammal stratum there is a bed of shells 8 inches thick, from which Doctor T. W. Stanton has identified *Unio* sp., *Sphærium* sp., *Goniobasis tenuicarinata*, *Planorbis* sp., *Viviparus* sp., *Campeloma* sp., which he says are suggestive of Fort Union rather than earlier forms."

Matthew (1914, p. 388) has checked up Brown's identification of the mammals and agrees with his findings and conclusions. He says in addition, in speaking of the apparently Palæocene element in the fauna:

> "I suspect that it will be found to compare more nearly with the Fort Union fauna. It is evident at all events that there was a considerable element of placental mammals in the fauna. But the Multituberculates are those of the Lance and some of the Trituberculates appear to be identical. There is no indication of the presence of any of the Eocene orders of placentals."

Comparison with the Fort Union fauna.—A comparison of the Lance with the Fort Union brings to light a number of similarities and still more marked discrepancies. The Fort Union mammals are known from several localities, all of which, with one exception, are in the neighborhood of Fish Creek in Sweet Grass County, south central Montana, a region the importance of which was enhanced by Douglass' discovery of these interesting types.

Silberling (Stanton 1909, p. 261) separated the Fort Union into three members, of which number 1, the lowermost, and number 2, the intermediate, together constitute the softer, darker-colored shales and sandstones with a combined thickness of about 1300 feet, while the upper member, or number 3, consists of massive sandstones interbedded with shales, and is more than 4000 feet thick. The last member is identical with the whole of the Fort Union of Stone and Weed.

The middle member, Fort Union number 2, is the one wherein the most important mammal collections were made, and from a quarry 65 feet below the top of the formation on the east side of Bear Butte, Mr. Gidley has recognized the following (classification after Matthew):

MULTITUBERCULATA

Ptilodus montanus Douglass
" *gracilis* Gidley
" *serratus ?* (Marsh) [=*Cimolomys*]
" *formosus ?* (Marsh) ["]

INSECTIVORA

Pentacodon ? sp.
Myxodectes ? sp.

CARNIVORA

Creodonta
Chriacus sp.
Oxyclænus sp.
Tricentes ? sp.
Deltatherium ? sp.
Didymictis sp. nov.

TÆNIODONTA

Psittacotherium sp.

CONDYLARTHRA

Mioclænus sp. nov.
Euprotogonia sp. nov.

TALIGRADA

Ectoconus ? sp. nov.
Pantolambda sp.

Matthew (1914, p. 389) adds to this list:

? MARSUPIALIA

? Batodon sp.
? Cimolestes sp.
? Peratherium sp.
Picrodus silberlingi Douglass

INSECTIVORA

Coriphagus montanus Douglass
Megopterna minuta Douglass

CARNIVORA

Creodonta
Protochriacus sp.

TALIGRADA

Anisonchus sp.

The two doubtfully determined species of *Ptilodus* described by Marsh as *Cimolomys* occur in the Lance of Niobrara County, Wyoming. All the other species in Gidley's list show affinities with the Torrejon fauna of New Mexico.

Clænodon ferox (Cope) and *Pantolambda cavirictus ?* Cope were obtained in Fort Union number 3, with an abundant Fort Union flora. Both *Clænodon* and *Pantolambda* are typical Torrejon genera. Comparing the mammals of the upper Fort Union with those of the Torrejon, Matthew says (1914, p. 392) that they appear "to be of the same age, as indicated by the identity of a part of the fauna. But it [Upper Fort Union] apparently represents a somewhat different facies, with certain points of analogy to the Lance."

The Lance mammals, wherever they are found, generally lie in more or less close association with ceratopsian skulls, and I have no doubt that such highly specialized members of the dinosaurian phylum represent very limited environmental conditions, whatever their nature may have been. The inference is therefore natural that the known mammals do also, and hence may not represent very completely the full aspect of mammalian life at that time. Exception has been taken to this statement, as the mammals are associated with an abundance of fresh-water fish scales, and as all are comminuted it means that the bones are drifted from a long way. Therefore one may have all sorts of mammals here. The ceratopsian skulls, from the extensive cavities which they contain and which must have filled with the gases incident to decay and thus become highly buoyant, were doubtless also extensively drifted, a point which the almost invariable lack of teeth in the upper jaws corroborates. Hence it would seem as though the fossil contents of these beds may have been the accumulation of the moribund flotsam of a considerable area, but still possibly of comparatively uniform environmental aspect. The wonderful preservation of the tiny cusps of many of the mammalian teeth does not indicate extensive rolling or disturbance after they were shed from the drifting carcass, but on the other hand, many of the sliver-like bone fragments found point to the dry disintegration of the bones before burial. Were the full Lance fauna known, it is probable that more of the precursors of the basal Eocene mammals would be found therein.

Summary.—To summarize: the Lance mammals are far removed in time from those of the Morrison, but because of the persistence of certain static Mesozoic types and the absence of known Tertiary forms in the former, there is a nearer resemblance in general character than between the Lance and basal Eocene. Comparison between the Belly River and the Lance is less satisfactory because of the dearth of mammalian fossils from the former and older formation, but, as Matthew says (1914, p. 391), the fauna of the Belly River is of the same facies (faunal aspect) as the Lance, despite the gap represented in the progressive evolution of the Ceratopsia and other dinosaurs. The Belly River mammals are doubtfully more primitive in stage and there is no good evidence of any change of fauna or of the appearance of any new immigrant groups. This last apparent fact may be due, however, to the dearth of our knowledge of Belly River types.

The Paskapoo and the Lance correspond closely in certain aspects of their faunæ, in that they have several types in common. These are, however, persistent Mesozoic forms, while the distinguishing animals of the Paskapoo are of decided Palæocene aspect. The Lance and the Fort Union show certain types in common, but they are again the static Mesozoic phyla which have persisted through long ages with so little change. The general faunal aspect has changed as materially as with the Lance and Puerco and Torrejon, though, as Matthew says of the latter, it is not very clear whether the faunal difference is due to diverse local environments, or to a great movement of faunal migration, but a combination of both seems to fit the data more exactly. This would indicate that the apparent absence from the Lance of the more primitive and archaic groups of the Puerco-Torrejon fauna may be a matter of environment; but that the absence of the larger, more progressive and abundant Palæocene placentals from the Lance is to be ascribed to a migration movement after its close. The evidence on this point is, however, too scanty to be of any considerable weight.

Reconnaissance of 1914

The writer's visit to the Lance beds last summer was far too brief to be of material value, but it stimulated the gathering of data as a basis for future work. The difficulty of securing exact information regarding the old collections has proved well-nigh insuperable, for the field records are very meager, and of those who collected the mammals in the Yale Museum, but one, Mr. Peterson, then at the beginning of his valued career as a practical paleontologist, is available for further information. Such as he has I have been able to utilize in full.

Our party entered Wyoming from Sioux County, Nebraska, following the course of Indian Creek nearly to its source, then over the divide to Sage Creek, missing the Hat Creek post-office and Hatcher's old trail by turning north on the mail road to Warren instead. Hence we entered the Ceratopsia region from the east, making our camp on the Johnson Brothers' ranch at the point where their original dugout cabin lay, in a small tributary canyon which entered that of Buck Creek from the east and a mile or more from the confluence. Mr. Doneghy, who accompanied me, took up the task of running a section from Buck Creek west toward Lance, while I spent the time in exploration, trying by means of Hatcher's map to locate both geographically and stratigraphically the more important ceratopsian and mammalian localities. The map proved to be very sketchy, and the exact identification of localities worked twenty or more years before in a complex of topographic features was a matter of extreme difficulty.

Several of the larger counties of Wyoming have lately been divided into two or more portions, including the old county of Converse. Here the division runs north and south, a little east of the mid-line. The name Converse is still retained for the somewhat larger western part, while the Niobrara River which rises in the eastern portion has given its name to the remainder. It so happens that the entire area of the "Converse County beds," which were embraced by the old political division, lies in the present Niobrara County, hence the inappropriateness of the older formation name.

Niobrara County is crossed from east to west by an important watershed, Pine Ridge, which continues eastward into Sioux County, Nebraska. South of this ridge, the land, with an average elevation of about 5000 feet, is drained by the Niobrara, although two small tributaries of the Platte rise in the southwestern portion. North of Pine Ridge the land falls abruptly for about a thousand feet, and is drained by the Cheyenne or its tributaries. Of the latter, Lance and Lightning creeks, together with Buck and Sage creeks, are the most important, the first mentioned giving its name to the formation. The map presented herewith (figs. 1 and 2) has been compiled largely from the General Land Office map of the state of Wyoming bearing the date of 1892, with such additions as Hatcher's field maps, thrice published (1896, 1907) seem to imply. This map has been submitted to Mr. Peterson for revision as to localities, but is only tentative and merely serves as a means of recording such otherwise perishable information as we now possess. It will show quite clearly the general relation of the Lance beds to the drainage, but the indicated boundaries of the formation, although based upon Hatcher's map, are only approximate, as the line of demarcation between the Fox Hills and Lance on the one hand and the Lance and Fort Union on the other is not clearly defined. As one approaches the locality from the east from Sage Creek, he climbs a gentle declivity for a distance of about 2 miles until near the summit of the divide separating the valley of Sage Creek from that of the parallel-flowing Buck Creek. Here the first escarpments are seen, of yellow sandstone, capped by hard brown concretionary masses and containing marine Cretaceous shells. From this divide several smaller canyons run with a general western trend to the bed of Buck Creek itself. These canyons are divided by pine-clad hills, with cottonwoods here and there along the water courses. In one such canyon near a strongly alkaline spring we pitched our camp.

From Buck Creek the land rises rapidly toward the west and north until the summit of the divide separating the watershed from that of Lance Creek is reached, when the land again descends to the latter stream. This area is grassed over, cottonwood trees following the main courses so that the latter are thus clearly indicated. Here and there are fairly deep tributary canyons where the ever-varying stratigraphy may be traced. The beds are alternating shales and sandstones with occasional bands of lignite. The sandstones in the canyons were mostly fairly hard, yellowish to whitish, often much cross-bedded and capped with a much harder brown sandstone, which often had the appearance of concretions. Some of the "concretions"

FIG. 1.

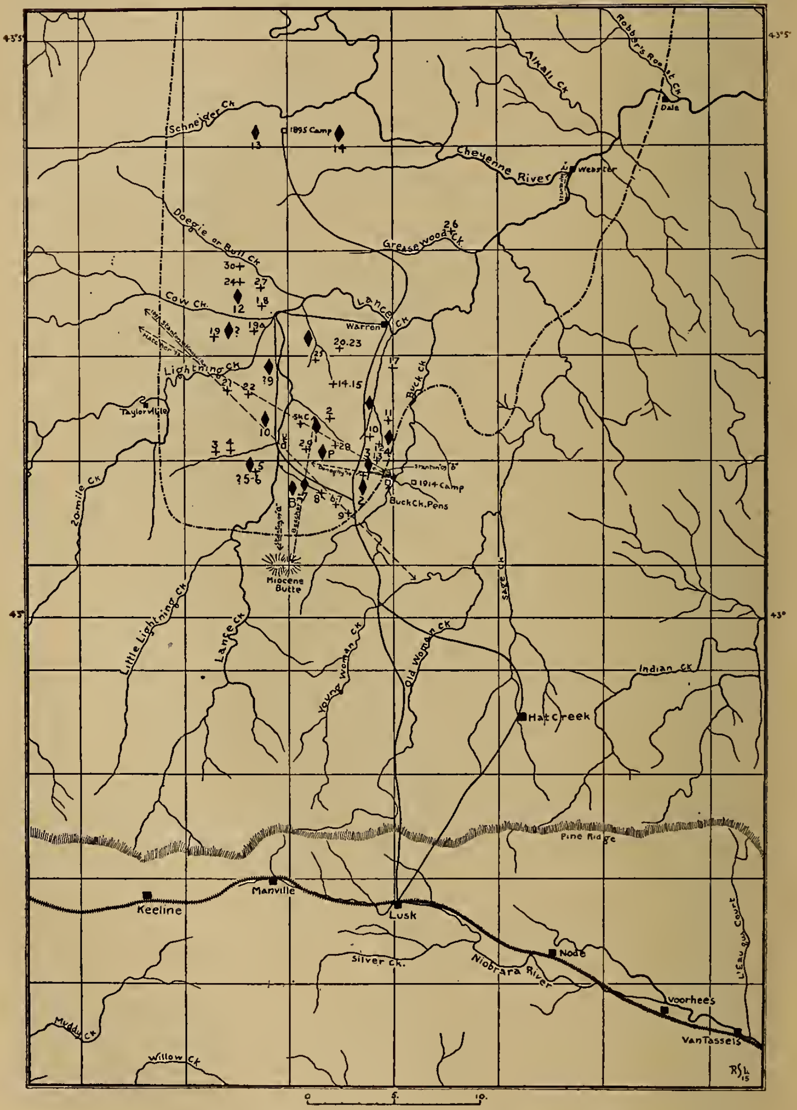


FIG. 1. Map of Niobrara Co., Wyo. Diamonds indicate mammal localities; crosses, ceratopsian skulls; broken and dotted line, limits of Lance formation.

FIG. 2.

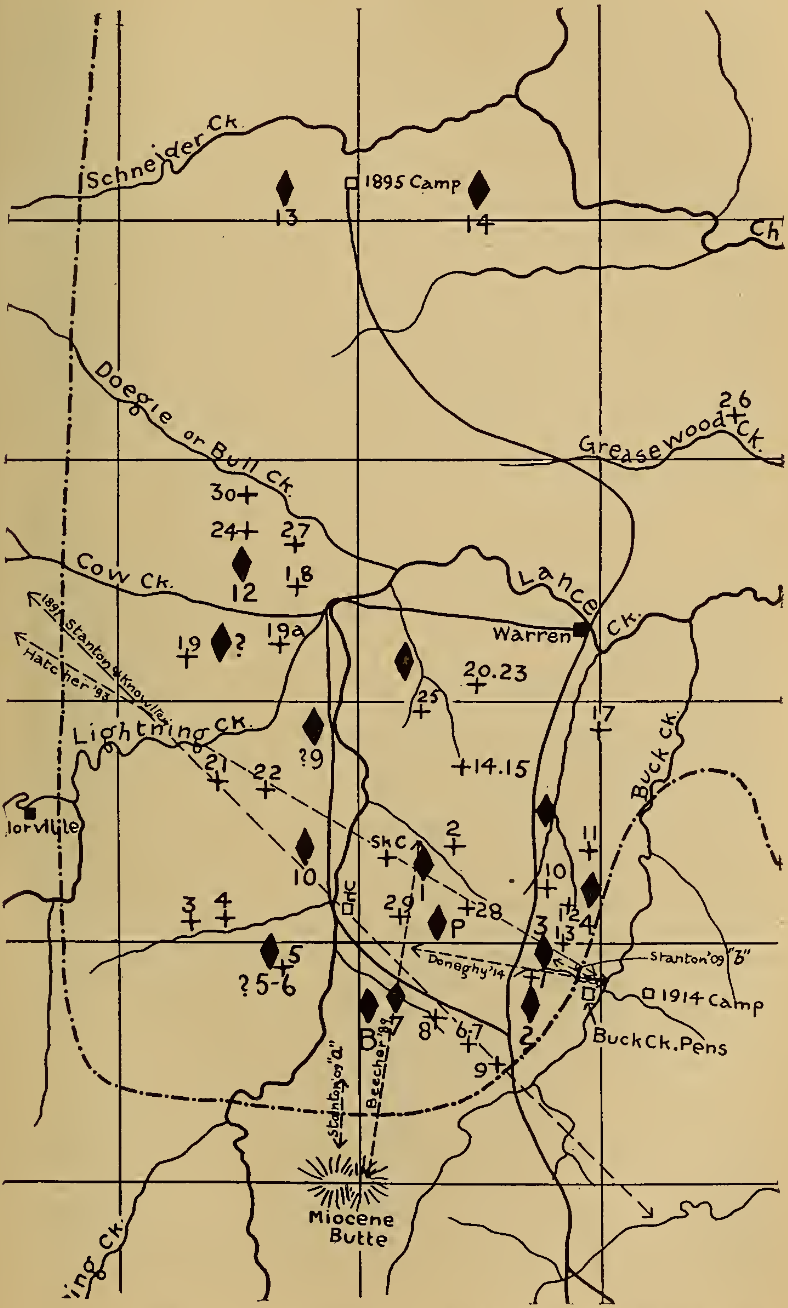


FIG. 2. Detail from the preceding map, showing the principal area of the Ceratops beds on a larger scale.

were longitudinally fluted and many feet in length. There were bands of softer clays often at the same level as the sandstone, but local in extent. This rapid change in the character of the deposition, which has been noted by previous observers, greatly complicates the task of unravelling the stratigraphy, as no two sections taken at different places in the region agree.

East of Buck Creek the sediments are marine and of Pierre age. Overlying the Pierre is the Fox Hills, again marine, and Stanton had no difficulty in finding the line of demarcation clearly indicated. We were not so fortnnate. West of Buck Creek the sediments are still of Fox Hills age and, so far as one can see from the physical evidence, they pass without a break in the deposition into those of the Lance formation. Nor can one tell, except for the contained fossils, to which series the sediments belong, and as there are some 400 feet devoid of fossils, which have at different times been referred to each, the precise limitation of the Fox Hills and Lance has been subject to dispute.

Knowlton (1909, p. 205) thus describes the area:

> The "Ceratops beds" are very limited in extent, extending about 15 miles from east to west, by 30 from north to south. The beds "are best exposed along the eastern and southern borders of a synclinal basin, and according to Hatcher are 3000 feet in thickness, though Dr. T. W. Stanton and myself, when we visited the area in 1896, concluded that they could hardly exceed 2000 feet, but as a large portion of the beds are exposed at a low broad angle in a broad flat grassy plain, it is impossible to measure the beds with a great degree of accuracy. The entire section of the region, which begins with several hundred feet of soft, bluish shales of the Pierre, up to and including the acknowledged Fort Union, was supposed by Marsh and Hatcher to be one of continuous deposition; that is to say, no actual unconformity had been detected. The Fox Hills, with an estimated thickness of 500 feet, consists of an alternating series of sandstones and shales. The massive sandstones at the top contain numerous large concretions and a rich marine fauna of characteristic Fox Hills species. The line between the Fox Hills and the overlying beds is a difficult one to draw, Hatcher, at first, placing it arbitrarily at a six-inch band of hard sandstones which separates the fossil-bearing Fox Hills sandstone below from the very similar but non-fossiliferous sandstones above.
>
> "Later, however, Hatcher appears to have changed his mind regarding the lower limits of the 'Ceratops beds,' for he says:
>
> 'At no place in the Converse [Niobrara] County region do the true Ceratops beds, with the remains of horned dinosaurs, rest upon true marine Fox Hills sediments; nor are the Ceratops beds in this region overlain by strata which could be referred without doubt to the Laramie.' This point was apparently well taken, for Stanton and I found four species of brackish-water in-

vertebrates in clays above a forty-foot bed of massive sandstone over 400 feet above the highest fossiliferous Fox Hills horizon in that particular section. The fact remains, however, that the fossiliferous portion of the 'Ceratops beds' is mainly the upper portion, the highest point at which dinosaurs were found, being only 100 to 150 feet below the Fort Union."

On the east side of the deposits, according to Hatcher, near Buck Creek the dip of the strata is about 16° N.W., whereas at the southwestern corner of the area between Twentymile and Little Lightning creeks it increases to 29° N.W. Our own observations, taken not far from the first mentioned place, gave a dip of about 10°. As one mounts the divide toward the west he crosses the entire section, for the slope beyond the summit practically coincides with the dip, so that no further exposures are seen except in the canyons. Bearing this in mind, if the localities of the ceratopsian skulls are at all accurately placed upon the map, they would seem to range through nearly the entire Lance formation, provided the lower 400 feet of non-fossiliferous sandstones belong to the Fox Hills (*vide supra*, p. 332).

Stratigraphy of the Lance Formation

The sections which have been recorded from the Niobrara County area are six in number, and may be described as follows:

1. Beecher's section, 1889.—This, a sketch section by Professor Beecher, runs approximately north and south, was taken east of Lance Creek, and covers a distance of about 8 miles. It was not published but I find it in a letter addressed to Professor Marsh and bearing the date of July 28, 1889. This section, together with a smaller one at Mammal Quarry No. 7 (map, ◆7), is here shown (figs. 3, 4). It shows two distinct levels where mammals have been found, one near the middle of the section, the locality of the so called Quarry No. 7, and the other at the top of the section at Quarry No. 1 (map, fig. 2, p. 331, ◆1). In each instance the mammal-bearing horizon will be seen immediately to overlie a bed of lignitic shales. Quarry No. 7 is also shown in the smaller section and lies in a canyon 30 feet in depth, tributary to Lance Creek on the eastward side. Beecher says of it (letter of July 28, 1889):

> "We have also found another locality where the mammals are in place and it gives promise of furnishing more bones and jaws than have yet been seen. The sandstone is so soft and friable, however, and the bones so brittle and checked that it will be very difficult to save the specimens. The horizon is much lower than either Quarry No. 1 or Peterson's quarry. The following section shows its position. It lies at the base of a stratum of

Figs. 3 and 4.

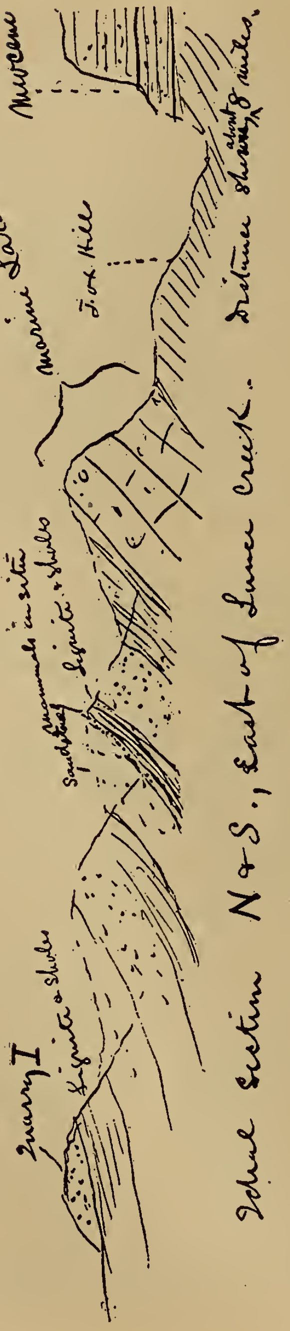


Fig. 3. Beecher's section of 1889 in the Ceratops beds. Fig. 4. Section at Quarry No. 7. From photographs of the original drawings.

sandstone and is from 1 to 3 feet thick. The bones and teeth are mingled with sand, nodules of clay and several varieties of fossil nuts."

2. *Hatcher's section, 1893.*—Hatcher (1893, p. 137) thus describes the area:

"The Ceratops beds are made up of alternating sandstones, shales, and lignites, with occasional local deposits of limestones and marls. The different strata of the series are not always continuous, a stratum of sandstone giving place to one of shales and *vice versa*. This is especially true of the upper two-thirds of the beds. The lack of continuity in the different strata has rendered it well nigh impossible to establish any definite horizons in the upper members of the series. All the deposits of the Ceratops beds of this region bear evidence of having been laid down in fresh waters. . . There is no evidence that marine or brackish-waters have ever had access to this region since the recession of the former at the close of the Fox Hills period.

"The sandstones largely predominate in the lower members of the beds. They are always fine-grained, massive to well-stratified, and nearly white to yellowish brown in color. They are occasionally compact and hard, but for the most part quite soft and friable. They are composed of sharp, angular grains of quartz with some clay and mica, the whole being loosely cemented together with carbonate of lime. Almost everywhere in the sandstones are numerous concretions of varying size and shape. Some are almost perfect spheres and vary from the size of a marble to 18 to 20 feet in diameter. Others are from a few inches to several feet in transverse diameter and sometimes several hundred feet in length, a cross section forming a nearly perfect circle. Others still are very irregular in form. These concretions usually show no concentric structure, and while they sometimes enclose foreign objects, as a *Triceratops* skull or a single bone as a nucleus, they are for the most part simply centers of solidification and not true concretions. This is frequently shown by the cross-bedding in them, so often seen in the sandstones themselves.

"The shales are almost entirely wanting in the lower 400 feet of the Ceratops beds, but they are well represented in the succeeding series. They are quite soft and loosely compacted, composed mostly of clay with more or less sand in places. The prevailing color is dark brown, but they are sometimes red or bluish. They are well stratified and finely laminated, and contain occasional limestone concretions enclosing numerous invertebrates.

"The lignites occur in thin seams, never more than a few inches thick, of only limited extent, and with many impurities. At no place in the Ceratops beds of this region have workable coal beds been found. These do occur, however, in the Ceratops beds of Montana . . . .

"Intercalated with the sandstones, shales, and lignites, are quite local deposits of limestones, clays, and marls. The latter are composed almost entirely of fresh-water shells, fragments of bone, teeth, etc.

"Along their southern and eastern border, the Ceratops beds dip to the northwest, at an angle of about 16° between Buck Creek and Lance Creek. One half mile east of Lance Creek, the dip is 29° to the northwest. This angle of inclination rapidly diminishes toward the interior, and is scarcely noticeable in the vicinity of Lightning, Cow, and Doegie creeks. The fold is quite abrupt as is further shown by cracks which were made in the strata at the time of disturbance at right angles to their dip and parallel with their strike. These fissures have been filled by infiltration with materials now harder than those forming their walls, and now appear in many places as projecting veins, from a fraction of an inch to a foot or more in width, and from a few yards to several hundred in length."

The section was that shown by the exposure made by a small tributary emptying into Buck Creek, four miles east of Lance Creek and a half mile northwest of the Buck Creek pens used by the cattle men for round-up purposes. This watercourse has cut its way in a southeasterly direction at right angles to the strike, down through the lower half of the Ceratops beds, through the underlying Fox Hills sandstones, and into the Ft. Pierre shales. All the strata of this entire section dip to the northwest at an angle of 16°.

The section (p. 139) is as follows:

	FEET
Alternating sandstones, shales, and lignites, fossiliferous	2600
Almost white, fine-grained, massive sandstones with numerous concretions, no fossils, about	250
Yellowish brown, well stratified sandstones, apparently non-fossiliferous, about	150
Hard sandstone layer. Arbitrary Fox Hills–Ceratops beds line	½
Sandstones and shales. Shales predominant in lower portion, toward middle the sandstones in excess, upper 50 feet entirely sandstones. Sandstones yellowish brown, very fine-grained, firm, well stratified below but softer and quite massive at top, where they contain concretions and a Fox Hills fauna	500
Pierre shale	

Stanton and Knowlton's sections.—Two sections, which have been described by Stanton and Knowlton (Stanton 1910, p. 185), lie at the south end of the area, about 30 miles southwest of the mouth of Lance Creek. Of the first one of them (*a*) Stanton says:

> One of these lies about 2 miles east of Lance Creek nearly opposite the mouth of Little Lightning Creek, and shows excellent exposures of Pierre, Fox Hills, and the lower part of the

Lance formation, all dipping northward 14° to 19°. No attempt was made to obtain a detailed section of the Lance formation, but a measurement across the strike as far as the strata have steep dips shows a thickness of about 1700 feet above the upper white sandstone, which was later determined to be the top of the Fox Hills. To this should be added perhaps 400 or 500 feet for the thickness of the nearly horizontal upper strata of the Lance formation. The lowest point at which dinosaur bones were seen is about 300 feet above the top of the Fox Hills."

The section follows:

	FEET
Gray sandstone	10
Shale	25
Sandstone and shale	20
Shale and coal	15
Shale with brackish-water fauna	20
TOP OF FOX HILLS.	
Massive white sandstone with brown concretions	40
Shaly sandstone	5
Coal and carbonaceous shale	15
Massive white sandstone	60
Shale	8
Sandstone	10
Shale	5
Massive white sandstone	100
Brownish gray sandstone in alternations of massive and more thinly bedded	130
Gray sandstone	30
Brown sandstone	20
Yellowish sandstone with Fox Hills fauna	30
Pierre shale	

Of the other section (*b*) in the southern end Stanton (1910, p. 186) speaks thus:

"The last section examined and perhaps the best exposed and most instructive of all is on Johnson Brothers' ranch, near Buck Creek, about 8 miles east of the section just described."

This section follows:

	FEET
Sandy shale with thin beds of coal	25
TOP OF FOX HILLS.	
Massive white sandstone with *Halymenites major*	60
Yellowish massive sandstone with brown concretions	20
More thinly bedded brown sandstone with *Halymenites*	25
Massive white sandstone	75
Soft somewhat sandy shales with thin sandstone bands containing marine Fox Hills shells	30
Brown shaly sandstone	5
Massive white sandstone	60

Thin-bedded brown and gray sandstone	130
Yellowish massive sandstone with concretions containing Fox Hills fauna	100
Pierre shale	

Stanton and Knowlton's sketch section of 1897 (p. 131) is reproduced in Figure 5.

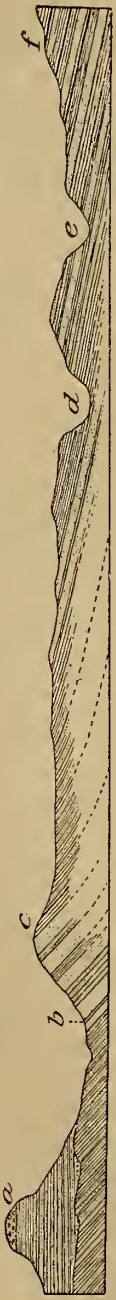
Stanton's section (c), 1909.—In 1910 (p. 184) Doctor Stanton gives an additional section in this area, taken on the south side of the Cheyenne River at the mouth of Lance Creek, and extending up the creek a mile and a half or two miles. It is as follows:

	FEET
White cross-bedded sandstone with irregular brown indurated bands, masses, and concretions	50
Soft sandy shale with bands of lignitic shale. Fragments of dinosaur bones were found on the surface here	50
Sandy shale full of *Corbicula cytheriformis?* and *Corbicula subelliptica* var. *moreauensis*	½ to 1
More or less carbonaceous shale	15
Soft massive gray sandstone with many brown concretions	25
Gray sandstone and sandy shale with bands of sandstone containing Fox Hills fossils, about	150
Cross-bedded, ripple marked, reddish brown sandstone with irregular base	8 to 10
Massive soft buff sandstone with many large concretions and indurated masses and an abundant Fox Hills fauna	100
Pierre shale with only the top exposed	

Stanton says further of this section:

"When studying the section it was believed that the upper four members belong to the Lance formation, but afterward when comparison was made with sections at the south end of the field it seemed more probable that all the beds

FIG. 5.



Section across the Converse County area of Ceratops beds. (*a*) Fresh-water Miocene resting unconformably on Fort Pierre; (*b*) Fox Hills; (*c*) Base of Ceratops beds and horizon of brackish-water Laramie fossils; (*d*) Lance creek; (*e*) Lightning creek; (*f*) Horizon of Fort Union plants. From Stanton and Knowlton, 1897.

examined here belong to the Fox Hills. The higher unquestioned Lance formation was not studied at this place."

Knowlton (1911, p. 372), however, says of the section under consideration :

"The section made on the south side of the Cheyenne River at the mouth of Lance Creek shows a thickness of 405 feet of Fox Hills above the Pierre, but the highest point in the section at which marine Fox Hills invertebrates were found is over 100 feet below the top. It further appears from this section that the upper four members, aggregating 115 feet in thickness, contain carbonaceous and lignitic shales as well as fragments of dinosaur bone and brackish-water invertebrates, certain of which are the same as those found in, and there said to indicate the Laramie age of, the 400 feet of beds already mentioned as reported by Stanton and Knowlton above the typical marine Fox Hills. To the writer [Knowlton] it seems altogether more probable that the four upper members of this section belong to the Lance formation and not to the Fox Hills. . . If this portion of the section is placed in the Lance formation, where it certainly appears to belong, the thickness of the Fox Hills in the section is reduced to 285 feet, or but little more than half of the maximum thickness assigned to beds of this age in the Converse County region. While this evidence may not be considered conclusive, it must at least be admitted that it strongly suggests the possibility that even here, as in the areas already discussed in the Dakotas and Montana, the Fox Hills is of variable thickness, due to the erosion of the upper portions before the deposition of the Lance formation."

Doneghy's section, 1914.—Mr. Doneghy's section, prepared in the summer of 1914, begins in very nearly the same place where Stanton's section (b) and that of Hatcher in 1893 were taken, that is, in the canyon of Buck Creek near the mouth of the draw mentioned by Hatcher and a short distance north of the Buck Creek pens. While it was occasionally necessary to depart to the right or left of a straight line in order to follow the exposures, the general trend of the section was N. 80° W. It was continued up the slope across the successive outcrops until the summit of the divide between Lance and Buck creeks was reached. Thence west to Lance Creek the general slope of the land surface, which is about 10°, approximately coincides with the dip, so that practically nothing further can be learned. Mr. Doneghy did not go west of Lance Creek. This section is more detailed than any of the others and hence is hard to compare with them. Our supposition was that the lignite beds were necessarily Lance, so that the horizon "*" about 200 feet above the bottom of the section was taken as the possible line of demarcation between the Fox Hills and the Ceratops beds. Productive ant hills and the remains of dinosaurs were found at a level some 300 feet higher, which is in agreement with the statement by Stanton (*vide supra*, p. 337).

Doneghy's section follows:

	FEET	
Gray sandstone, poor or no outcrops, surface slope approximating that of beds ± 10° W.	125 to 150	600
Massive hard gray sandstone, often capped by huge concretions, productive ant hills, probable level of Quarry No. 2 (Skull No. 1)	9 to 10	
Lignite, dinosaur bones at top	18	
Buff concretionary sandstone, ? possible limit of Fox Hills	1	
White concretionary sandstone	8 to 9	500
White sandstone with interbedded lenses of shale and lignite, massive in appearance but weathering brings out extremely irregular cross-bedding, concretions scarce, poor outcrops, ant hills barren	75 to 100	
Hard red sandstone, cross-bedded, jointed, slightly flexed	3	400
Massive gray sandstone, bedding like above	12	
Talus of soft sandstone, shale and lignite, no outcrop	45 to 50	
Hard sandstone, much cross bedded but regularly bedded	3	
Soft sandstone, poor outcrop	7	
Hard red bed, massive in appearance, but seems to weather into thin dirty brown slabs. Unweathered layers show no sign of bedding, about	2	
Red beds, irregular bedding	2	
Hard buff massive sandstone	10	
Thin-bedded, even-bedded, hard sandstone	4	
Sandstone	12	300
Alternating soft shale and lignite	20 to 25	
Massive buff sandstone	20	
Hard buff concretionary sandstone	10	
Alternating soft buff sandstone and red shale, with plant and bone remains, beds average 1 foot in thickness, about	16	
Lignite bed, about	4	
Resistant pink concretionary sandstone	0½	
*White to gray massive sandstone	15 to 20	200
Hard red sandstone	1	
Sandstone in alternating beds, 6 inches to 10 feet, occasional hard and concretionary layers	75 to 79	
Red sandstone, about	2	
Thick-bedded sandstone	15 to 18	
Soft alternating shales and sandstones in beds 1 to 5 inches thick, varicolored	10	100

Soil and talus		8	
Resistant white concretionary sandstone, a ledge maker	1 to	2	
Hard white massive sandstone, regularly bedded		15	
Alternating white to brown sandstone, in beds 1 inch to 1 foot thick, regularly bedded		10	
Very hard brown sandstone, concretionary, shark tooth, about		1½	
Resistant white sandstone		1½	50
Soil and talus		17	
Massive white sandstone	6 to	8	
Soil cover		17	
Massive irregularly bedded buff sandstone		8	

Ceratopsian Localities

Geologic sequence.—As a result of the labors of Mr. Hatcher and his aids, no fewer than thirty-two ceratopsian skulls in varying degrees of preservation were brought to light, in addition to several partial skeletons. This material was studied in part by Professor Marsh and later, in preparation for the Ceratopsia monograph, by Hatcher and Lull. The collection, therefore, includes every Lance ceratopsian type and nearly all of the figured material, so that its importance can not be overestimated. The material is now about equally divided between the United States National Museum and that of Yale. The collection of the former institution is entirely prepared, while upon the Yale material there is still much to be done. The skulls were given a series of numbers, 1–19, and 19A–31, making thirty-two all told, while the skeletons were indicated by letter, skeleton C and skull 26 constituting the composite mounted *Triceratops* at the National Museum. Professor Marsh and Mr. Hatcher naturally chose the best specimens for description, with the exception of the type of *Triceratops horridus*, which is Skull No. 1, and one or two others. Circumstances were such that the skulls of the upper levels were the best preserved, so that with the exception of skulls Nos. 1 and 9 (*Triceratops obtusus*), which are the lowest in the series, most of the types come from the upper portion and are all quite near one another stratigraphically, while between No. 1 and the next higher known form there are a number of unidentified and indeterminable specimens, which may or may not have their representatives in the higher levels.

I have arranged the skulls in their stratigraphic sequence, based upon all the data available at present, but taken very largely from a study of the map, and the tables will show not alone the ceratopsian sequence but that of each adjacent mammal quarry as well. I place rather less value upon an evolutionary sequence of ceratopsian species within the Lance than I did some years ago (1912, p. 774) as there seem to be more lines of descent than were recognized at that time.

Evolutionary sequence.—Lambe (1915)* recognizes three main phyla of Belly River Ceratopsia, two of which lead into the two main groups of Lance forms, the third extending perhaps into the Edmonton but not as yet recognized in the Lance. He dismissed for the present the old Judith River genera *Monoclonius* and *Ceratops* as being insufficiently characterized. Brown (1914B, p. 550), however, considers Lambe's genus *Centrosaurus* to be the equivalent of the former. According to Lambe, the separation of these three phyla based upon the main characteristics of the horn-cores and neck frill, appears to be as follows:

*****Eoceratops* to †*Triceratops* [also †*Diceratops*]
Large brow-horn increasing in size.
Nasal horn persistently small.
Squamosal broadly triangular.
Parietal fontanelle disappearing (closing).

** *Centrosaurus* [= *Monoclonius?*], ***Styracosaurus*, and ***Brachyceratops*. ‡
Brow-horn persistently small.
Nasal horn persistently large.
Squamosal continuing small.
Parietal fontanelle diminishing.

** *Chasmosaurus* to †*Torosaurus*
Brow-horn increasing.
Nasal horn decreasing.
Squamosal lengthening.
Parietal fontanelle diminishing.

In the Lance, therefore, there are two distinct series (Lull 1912, p. 774), the *Triceratops-Diceratops* race and that of *Torosaurus*. The latter is extremely rare and contains but two species, which may prove identical, as they are very similar and from nearly the same locality, though separated by a stratigraphic interval of about 200 feet.

Diceratops, with the obsolete nasal horn, represents an aberrant race of the *Triceratops* series, while of the genus *Triceratops* itself I can recognize two well-defined phyla and some additional species difficult to place. Of these the first phylum is represented by *Triceratops prorsus*, characterized by a well-developed nasal horn pointing forward, and moderate brow-horns. The race includes *T. prorsus*, the closely allied

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* Geol. Surv. Canada, Mus. Bull. 12, p. 15.

† Lance.

‡ Two genera described by Brown from the Edmonton seem to belong to this group: *Anchiceratops*, showing affinities with *Styracosaurus;* and *Leptoceratops*, with *Brachyceratops*.

** Belly River.

TABLE 1.

U. S. N. M. skulls, other than types, identified by Gilmore. Yale skulls, other than types, identified by Lull.						Phyla					
Level	Sk. No.	Mus.	Cat. No.	Type	Genus and species	Torosaurus	Diceratops	Triceratops prorsus	Triceratops elatus	Miscellaneous	Nearest (stratig.) mammal quarry
High 1	19	Y.M.	1830	Holo.	*Torosaurus latus*	x					?
2	31	Y.M.	1838		*Triceratops* sp. indet.						
3	19A	Y.M.	1831	Holo.	*Torosaurus gladius*	x					
4	24	Y.M.	1828		*Triceratops "ingens"* MS.				x		12
5	30	Y.M.	1837		*Triceratops* sp. indet.						
6	18	Y.M.	1829		*Triceratops ?elatus*				x		
7	27	N.M.	5740		*Triceratops* sp. indet.						
8	21	Y.M.	1832	Ples.	*Triceratops ?brevicornus*			x			
9*	22	Y.M.	1834	Holo.	*Triceratops brevicornus*			x*			10 ?9
10	2	Y.M.	1821	Holo.	*Triceratops flabellatus*				x		
11	25	N.M.	2412	Holo.	*Diceratops hatcheri*		x				
12	16	N.M.	1201	Holo.	*Triceratops elatus*				x		27 18
13	20	Y.M.	1833		*Triceratops* (suggests *Diceratops*)		?x				
14	23	Y.M.	1836		*Triceratops?* sp. indet.						
15	26	N.M.	2100	Ples.	*Triceratops ?prorsus* or *elatus*				?x		
16	5	N.M.	4276	Holo.	*Triceratops sulcatus*					x	5
17	29	N.M.	4928	Holo.	*Triceratops calicornis*				x		P** 1
18	4	Y.M.	1823	Holo.	*Triceratops serratus*			x			
19	3	Y.M.	1822	Holo.	*Triceratops prorsus*			x			
20	14	N.M.	7239		*Triceratops* sp. indet.						?6
21	15	N.M.	1208		*Triceratops sulcatus*					x	
22	28	N.M.	6679		*Triceratops* sp. indet.						
23	10	N.M.	5741		*Triceratops elatus*				x		
24	17	N.M.	1205		*Triceratops prorsus*			x			
25	11	N.M.	4708		*Triceratops elatus*				x		
26	12	N.M.	4286		*Triceratops sulcatus*					x	
27	13	N.M.	2124		*Triceratops* sp. indet.						
28	8	N.M.	5738		*Triceratops* sp. indet.						B** 7
29	6	N.M.	2416		*Triceratops serratus*			x			
30	7	N.M.			Cannot find						
31	1	Y.M.	1820	Holo.	*Triceratops horridus*			x			3 2
32 Low	9	N.M.	4720	Holo.	*Triceratops obtusus*		?x			x	4

* Stanton says not much higher than skulls Nos. 3, 4, 5.

** P, Peterson's mammal quarry; B, Beecher's; the rest were numbered.

if not identical *T. brevicornus*, probably *T. serratus* and *T. horridus.* All are of moderate size with the exception of the last and their range in the stratigraphic column is low, especially as Skull 22 and possibly 21 in the table may be placed entirely too high.

Of the second *Triceratops* phylum *T. elatus* is typical. In this race the nasal horn is very small and set well back from the terminus of the beak; the brow-horns, on the contrary, are very large. To this group belong *T. calicornis*, closely related to if not identical with *T. elatus;* probably also the immature though large *T. flabellatus*, and the gigantic "Skull 24" to which Marsh gave the manuscript name of *Triceratops ingens.*

The members of this second phylum are all large and range through the middle and upper portion of the Lance. To derive them from the first phylum would necessitate the retrogression of the nasal horn to which certain critics (Gidley in Peale, 1912, p. 751) object, although the principle is certainly well established in evolution. I am willing, however, to accept Mr. Gidley's main contention of the improbability of the reduction of a highly developed nasal horn while the brow-horns were being developed to be the principal ones.

Mammalian Localities

The table of ceratopsian distribution also shows the nearest mammal localities stratigraphically to each skull, and has enabled me to arrange them in an approximate sequence which, however, is open to the same chance for error as that of the skulls in that it is derived largely from the study of the map and the sections. It should, therefore, be verified by further accurate field work.

One thing at least is certain, that instead of being confined to any one level, mammalian remains are found throughout nearly the entire Ceratopsia-bearing beds.

From Peterson's quarry, Beecher's quarry, and Quarries Nos. 1–10 we have a recorded mammalian fauna. From Quarries 11–27 there is no recorded material at Yale or at Washington, so that at present I am unable to give a list of genera and species from them. This is unfortunate, as the four quarries highest in the list are included within the number and a record of their mammalian contents would be of great interest.

There are also a number of species of which the types bear no quarry number but which are in part duplicated by unnamed material the source of which is indicated.

The following table gives Marsh's original genera and species and in the adjacent columns their distribution in the several quarries is indicated. I have also identified in so far as possible all the additional material from these quarries, with

TABLE 2.

T=holotype X=occurrence P=figured specimen	Mammal-bearing quarries High ⟵ Strat. sequence ⟶ Low											Not recorded	No. 8, loc. not known
	No. 10	No. ?9	No. 5	No. 1	Peterson's	No. ?6	Beecher's	No. 7	No. 3	No. 2	No. 4		
Suborder Trituberculata													
Stagodon nitor					T							P	
tumidus												T	
validus				P								P	
sp. indet.				X	X							X	
Platacodon nanus					T								P
sp. indet.			X										
Pediomys elegans				TP	P			X					
sp. indet.					X								
Batodon tenuis				P				P				P	
Didelphodon comptus		X	X	TP								?P	?X
ferox		X		TP									
vorax				TP								P	
sp. indet.				X	X							X	X
Cimolestes curtus	X			T									
incisus		X	P	TP				X				P	X
sp. indet.					X				X			X	
Telacodon lævis			T									P	
præstans												T	
Dryolestes tenax												T	
Genus novum		X	X										
Suborder Allotheria (Multituberculata)													
Allacodon fortis												T	
lentus		X	TP	X	P			X					
pumilis			?X	T									
rarus												T	
sp.			X										
Cimolomys agilis												T	
bellus		?X										TP	
digona	X	?X	T		P								
(*Halodon*) *formosus**	X				TP		X		X				X
gracilis				TP									
(*Nanomyops*) *minutus*				T				P	X				
sp.									X		X		
nitidus			P	T			P	P					
parvus				T				P					
(*Halodon*) *serratus**				T				?X	X		P		
sp.		X			X				X			X	
Meniscoëssus (*Selenacodon*) *brevis*		?X		T				X				P	
(*Tripriodon*) *caperatus*				T							P	X	
cœlatus				TP									
(*Selenacodon*) *fragilis*		X		T									
(*Dipriodon*) *lunatus*		X		TP					X			P	
robustus		X	X	P	P			X		T		X	
(*Halodon*) *sculptus*		P		TP		P	P		X		P		
sp.												X	
Oracodon anceps	X	X						P				T	?X
conulus												T	
Camptomus amplus				TP									

* Referred to *Ptilodus* by Gidley, 1909, pp. 622-623.

the exception of Quarry No. 1 and Peterson's quarry. The former particularly was an immensely prolific locality and there are yet at least eighty-five vials containing unnamed specimens at Yale and more at Washington from these localities. These additions have served very largely to amplify the table, especially from Quarries Nos. 10, 9, 5, 7, and 3.

Comparing this table with that showing the distribution of ceratopsian species, it will be seen that no mammals are recorded above the level of *Triceratops brevicornus* type, so that those which were associated with the huge *T.* "*ingens*" and with *Torosaurus*, if there were any such, are unknown. Turning again to the table, the great number of species from Quarry 1 must be due in part to a happy accident of preservation; nevertheless some species range from the level of Quarry No. 1 upward, others downward, while some of the commoner species like *Meniscoëssus robustus* and *M. sculptus* continue throughout nearly the entire series. One rather remarkable feature is brought out, however, in that the Trituberculates are rarely found below the level of Peterson's quarry; Quarry No. 7, which is very productive, and a lone specimen in Quarry 3 constituting the record. The Multituberculates, on the other hand, are as plentiful below the level of Quarry No. 1 as above. This may be significant, though the greater resistance to destruction offered by the more massive multituberculate molars may in part explain it.

The material the quarry of which is unrecorded probably came very largely from either Peterson's quarry or Quarry No. 1, if one may judge from the date of shipment as compared with similar dates in Hatcher's field diary, in which the work done is meagerly recorded. Quarry No. 8 I can not locate, but it may be one of two unnumbered mammal localities, one of which would bring it not far from the level of Beecher's quarry, the other between Quarries No. 5 and No. 10. The last would be more in keeping with the "trituberculate" distribution.

Summary

It will be seen that the results of the above study are inconclusive in some important details, which only serves to emphasize the need of exact field work covering the entire area. This should include a carefully prepared topographic map whereupon the sections and fossil localities could be plotted with great accuracy, while the paleontological task should be to search minutely the whole region from south to north, keeping a careful record of the exact occurrence of any mammal deposits stratigraphically. There is reason to believe that such exhaustive search would be rewarded by much more perfect material than any yet preserved. Possibly more complete jaws or even skulls and associated skeletal remains may be found, which alone will serve to put our knowledge of Lance mammals upon a more exact basis.

The main conclusions reached in the present paper are as follows:

1. That the mammals, instead of being confined to any one horizon, are pretty uniformly distributed throughout the entire Ceratopsia-bearing beds.

2. That the mammals are apt to be not far removed from lignitic deposits and are found in association with often worn scales and teeth of fresh-water fishes, generally in a bone conglomerate at the base of invading sands. This would seem to imply some transportation from the actual living habitat. The associated plant remains, both with the mammals and the Ceratopsia skulls, imply an abundance of vegetation, possibly forested conditions, in their respective homes, whether they differed or not.

3. That the more conservative and older Multituberculates range throughout the entire Lance, while the Trituberculates thus far found are absent from the lowermost quarries. This seems to be significant, for Multituberculates are known from the Jurassic and become extinct in the Palæocene, while descendants of the Trituberculates may still exist.

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Art. XXVII.—*A Note on the Qualitative Detection and Separation of Platinum, Arsenic, Gold, Selenium, Tellurium and Molybdenum;* by Philip E. Browning.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—cclxx.]

Probably the best working scheme for the qualitative separation and detection of platinum, gold, arsenic, selenium, tellurium and molybdenum is that of Noyes and Bray.* Briefly stated the method is as follows: the platinum is first separated as potassium chloroplatinate by evaporation with a potassium salt, and the arsenic in the filtrate is removed as ammonium magnesian arsenate by precipitation with magnesian chloride mixture in ammoniacal solution. The filtrate is then made acid with oxalic acid and warmed to precipitate the gold. The filtrate from the gold separation is evaporated almost to dryness and treated with strong hydrochloric acid and sodium sulphite, which removes the selenium, and on dilution of the filtrate and treatment with potassium iodide and sodium sulphite the tellurium is thrown down. After the removal of the tellurium and the addition of zinc and potassium sulphocyanide to the filtrate the red molybdenum sulphocyanide is obtained.

Recent work by a class of about forty in the application of this method to the analysis of a common solution showed a marked variation in results. With a considerable proportion of the class the tests for gold and arsenic were unsatisfactory and in some cases the tests for selenium and tellurium were doubtful. An investigation of the causes of these results revealed the following facts. First, that a solution of tellurous chloride when treated with a sufficient amount of ammonia to form the soluble ammonium tellurite and then with magnesium chloride mixture will give a flocky precipitate of magnesium and ammonium tellurite not easily soluble in an excess of ammonia. This reaction has been noticed by Heberlein† and use has been made of it by him in the purification of crude tellurium. Second, selenious acid when treated with ammonia and magnesium chloride mixture tends to give, especially on warming, a crystalline precipitate of magnesium and ammonium selenite also quite insoluble under the conditions. Both this compound and that of tellurium have been described by Hilger.‡ Third, a solution of gold chloride when treated with ammonia gives a precipitate of fulminating

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* Noyes and Bray, Jour. Amer. Chem. Soc., xxix, 137.

† Heberlein, Inaug. Dissert. Basel, 1898, 37. Gmelin-Kraut, 7th Edition, III (2), 859.

‡ Hilger, Ztschr. anal. Chem., xiii, 132.

gold; and after filtering and washing, gold may be detected both in the filtrate and in the precipitate.

From these facts it would seem probable that in the attempt to precipitate the arsenic acid as the ammonium magnesium arsenate one might under certain conditions not always easy to avoid, precipitate some of the compounds of gold, tellurium and selenium, and not only vitiate the test for arsenic but also partly destroy the delicacy of the tests for gold, selenium and tellurium.

To avoid these difficulties, one may leave the treatment with magnesium chloride mixture until after the gold, selenium and tellurium have been removed and detected. On evaporating with bromine or nitric acid, the filtrate from the tellurium, which contains hydrochloric, sulphurous and hydriodic acids, oxidation of the arsenic and molybdenum readily takes place, and the precipitation of the arsenic by magnesium mixture can be satisfactorily made. The molybdenum sulphocyanide is easily obtained in the filtrate by acidifying with hydrochloric acid and adding zinc and a sulphocyanide.

As a substitute for oxalic acid, hydrogen dioxide in alkaline solution has been found very satisfactory for the precipitation of gold.

In conclusion, it may be stated that the above indicated modification of the original method gave much more satisfactory results in the hands of the class.

June, 1915.

Art. XXVIII.—*On Aventurine Feldspar*; by Olaf Andersen. With Plates I–III.

CONTENTS.

INTRODUCTION.

Different varieties of feldspar show a more or less distinct metallic schiller, aventurization (sunstone schiller), when light rays fall in certain directions on cleavage faces or artificially polished faces. This schiller is caused by oriented lamellar inclusions which reflect the light with great intensity. The "fire" of the schiller is due to the brilliant interference colors produced by the thin film action of the reflecting lamellæ.

Aventurization may be defined as a play of light and colors caused by strong reflections from thin oriented lamellæ of visible size included in the feldspar.

The terms aventurine feldspar and sunstone have been used interchangeably by previous authors. It seems advisable to

Am. Jour. Sci.—Fourth Series, Vol. XL, No. 238.—October, 1915.
23

make some distinction between them by using aventurine feldspar as the general term, embracing all feldspars which show aventurization, without regard to the intensity of the phenomenon. Sunstone should then be the special term for those varieties which have intense aventurization and therefore sometimes find use as gem stones.

Aventurine feldspars (sunstones) should be sharply distinguished from the other group of color-playing feldspars known as moonstones, murchisonites and labradorites. These feldspars are characterized by a rather subdued, generally bluish or greenish play of colors ("glaukisiren"*) which is not caused by any visible lamellæ but perhaps by submicroscopic inclusions. The colors are probably due to scattering of light by particles smaller than the wave length of light,† and can not be explained as ordinary interference colors of thin films.

A survey of the literature shows that the conceptions of the problems connected with aventurine feldspars have been rather diverse. A general treatment of the subject based on thorough examinations of different aventurine feldspars has never been attempted. It, therefore, seemed of considerable interest to subject these problems to a somewhat closer study.

I had at my disposal good material from a number of occurrences. Specimens from Norwegian localities were obtained from the Mineralogical Museum of Kristiania University through the kindness of Professor Dr. W. C. Brögger and Mr. Jacob Schetelig. During visits to some of these localities I have also had the opportunity to collect specimens and to study their occurrences. From American localities I obtained good specimens from U. S. National Museum through the courtesy of Dr. G. P. Merrill and Dr. E. T. Wherry, who placed at my disposal (among other specimens) the entire feldspar collection of Isaac Lea, containing the type specimens for the paper referred to below.

PREVIOUS WORK.‡

Aventurine feldspars or sunstones are mentioned in some of the earliest systematic works on mineralogy,§ in which they are described as varieties of feldspars without explanation of the aventurization.

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* C. Viola, Zs. Kryst., xxxiv, 171, 1901.

† Cf. explanation of the blue of the sky, C. Viola, loc. cit., p. 188.

‡ The following review is not intended to be complete, the most important work only being mentioned. Some additional references will be found in different parts of the present paper.

§ e. g. Delametherie, Théorie de la Terre, vol. II, p. 201, 1797, where the term heliolithe is used.

R. Jameson, A System of Mineralogy, 1820, vol. II, p. 17, where aventurine feldspars from The White Sea and Archangel are mentioned.

Very little was known about the exact localities or the mineral associations of the sunstones. The first description of an occurrence was given by K. G. Fiedler,[*] who discovered a locality near Werchne Udinsk, Siberia. Fiedler does not describe the feldspar and the explanation of the aventurization is disposed of in the following remarks: "Ueber diesen Feldspath ist noch zu bemerken, dasz er seinen Goldschimmer der Vulkanität verdankt in welcher er entstand."

The well known occurrence at Tvedestrand, Norway, was discovered by Weiby in 1844. This locality has furnished a large quantity of good specimens, the first of which were carefully examined by Th. Scheerer,[†] who analyzed the feldspar (oligoclase) and described and gave drawings of the reflecting inclusions, which he determined as hematite. He found these inclusions to be oriented parallel to (001), (010), $(\bar{2}21)$ and a vertical prism and summarized his explanation of the origin of the sunstone as follows:[‡] "Man musz also annehmen, dasz Oligoklas und Eisenglanz die Producte eines gleichzeitigen Krystallizationsactes sind, und dasz beide, in ihrer regelmässigen Werwachsung ein dem Schriftgranite ähnliches Gemenge darstellen."

A. Kenngott[§] discussed the qualities of the reflecting lamellæ, and concluded that they were goethite ("pyrrhosiderit").

E. Reusch[‖] discussed, in connection with a careful study of moonstones, the problem of reflections and refractions in bodies like sunstones and moonstones and made a few observations on sunstone from Tvedestrand, correcting and supplementing some of Scheerer's measurements.

Isaac Lea[¶] made microscopic examinations of sunstones from different (mostly American) localities and described the reflecting inclusions, which were considered goethite, but did not attempt to determine their orientation, thinking that "they usually lie parallel with the principal cleavage of the feldspar."[**]

A. Schrauf[††] studied aventurization on labradorites and also examined the inclusions in sunstone from Tvedestrand. It was shown that the inclusions from the sunstone were identical with those found in carnallite, the latter determined to be hematite. The lamellæ causing aventurization on (010) of certain labradorites (which also showed labradorization) were found to be oriented approximately parallel to (180) and (170).

J. W. Judd,[‡‡] in discussions on the schiller of minerals,

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[*] Pogg. Ann., xlvi, 189, 1839.

[†] Pogg. Ann., lxiv, 153, 1845.

[‡] Loc. cit., p. 161.

[§] Sitz.-Ber. Akad. Wien, x, 179, 1853.

[‖] Pogg. Ann., cxvi, 396, 1862.

[¶] Proc. Acad. Nat. Sc. Philad., 1866, 110.

[**] Loc. cit., p. 111.

[††] Sitz.-Ber. math. naturw. Cl. Ak. Wien, lx, I, 1024, 1869.

[‡‡] Quart. Journ. Geol. Soc., xli, 374, 1885. Min. Mag., vii, No. 33, 81, 1886.

embracing aventurine feldspars, came to the following conclusion concerning the origin of the inclusions:[*] "These enclosures are of the nature of negative crystals which are more or less completely filled with products of decomposition of the mineral." Judd considered these products of decomposition as chiefly consisting of amorphous hydrates of silica and ferric oxide.

H. Tertsch[†] examined the sunstone from Tvedestrand and found the reflecting lamellæ oriented parallel to (538) and (417), which forms were considered boundary positions ("Grenzlagen") of the simpler form (213).

A. Johnsen determined the inclusions in carnallite[‡] and cancrinite[§] as hematite, and found them identical with those contained in aventurine feldspars. The presence of the inclusions in carnallite and cancrinite was explained as due to secondary reactions and unmixing in the solid state. It was intimated that the inclusions in aventurine feldspars might be explained in the same way.

I. METHODS OF EXAMINATION AND GENERAL RESULTS.

The study of the specimens embraced three groups of examinations:

(1) Microscopic examinations with the object of determining the feldspars.

(2) Determination of the orientation of the reflecting lamellæ.

(3) Examination of the properties of the reflecting lamellæ.

The results of the first group will be given in the section in which the specimens are described and details of all measurements are given. The present section contains a brief review of the general results of the last two groups in connection with descriptions of the methods applied and discussions of the simple optical problems involved.

Determination of the Orientation of the Lamellæ.

For a complete determination of the orientation of the lamellæ we must know both the coördinates of the different planes parallel to which the lamellæ are oriented and the directions of certain edges of the lamellæ. All orientation must be referred to some crystallographic planes or axes of the feldspar.

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[*] Quart. Journ. Geol. Soc., xli, 384, 1885.

[†] Tsch. Min. Petr. Mitt., xxi, 248, 1902.

[‡] Centralbl. Min., 1909, 168.

[§] Centralbl. Min., 1911, 369.

Planes of Orientation.

As the specimens consisted of cleavage pieces, in general showing no other faces than the cleavage faces (001) and (010), all measurements had to be referred to the elements (001) (010) and the *a*-axis.

In determining the planes of orientation of the lamellæ we have thus to deal with the following angle coördinates:

ρ_P = angle between P (001) and lamellæ.
ρ_M = angle between M (010) and lamellæ.
ϕ_P = angle between line of intersection : lamellæ $\wedge$ P (001) and *a*-axis.
ϕ_M = angle between line of intersection : lamellæ $\wedge$ M (010) and *a*-axis.

A combination of two of these angles determines the plane of orientation of a set of lamellæ.

To be able to refer the measurements to the proper octants in the axial system of the feldspar we must know the approximate direction of the *c*-axis (or the direction of the positive or negative *a*-axis) for each cleavage piece examined. In the plagioclases the difference between the obtuse and the acute edges of the *a*-axis must also be noticed. On specimens of microcline the perthite striation on (010) will generally indicate the approximate direction of the *c*-axis. In the plagioclases it is necessary to look for indications of the third cleavage, parallel to $(1\bar{1}0)$, or else to rely on the determination of extinction directions on small cleavage pieces chipped off from the larger.

The angles ϕ could be measured either with the microscope on oriented sections after (001) and (010), or with the goniometer on cleavage pieces. The angles ρ were always measured with the goniometer.

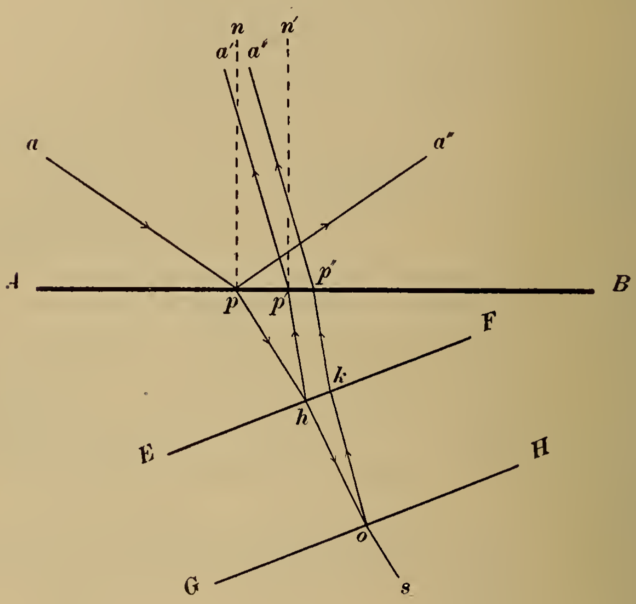
Measurements with the microscope.

The measurements of the angles ϕ on thin sections consisted in determining the angle between the cleavage lines and the lines of intersection of the lamellæ with the surface of the section. The latter lines we will call the section lines of the lamellæ.

As there were always more than one set of lamellæ to be measured, the difficulty in determining the orientation of each set by measuring the two angles ϕ would consist in a correct correlation of the measurements from the two different sections. For each set, the angle ϕ of which had been determined in one section, it was necessary to estimate the angle ρ in the same section in order to get an idea of the orientation of the lamellæ in space. It was then possible to identify the same set of lamellæ in the second section on which the other angle ϕ was to be determined.

A more detailed description of the microscopic measurements is unnecessary, especially since the method was only used in the preliminary work and in cases where the angles ρ of the lamellæ were too large to be measured with the goniometer.

Fig. 1.



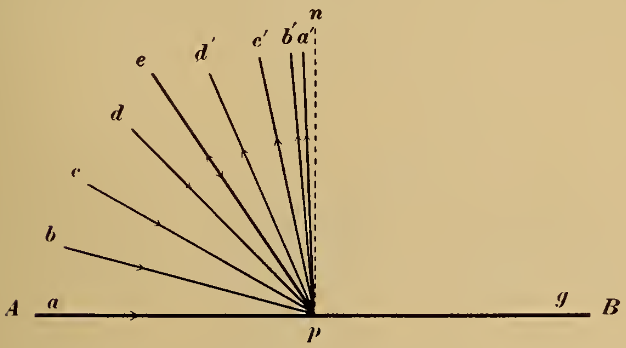
Some of the measurements will be recorded in connection with the description of the specimens.

Remarks on the Optics of Aventurine Feldspars.

Before describing the measurements with the goniometer a brief general discussion of the course of light rays in aventurine feldspars will be in place. We consider only rays in the main reflection plane, the plane perpendicular to the section lines of the lamellæ, as only such rays are used in the measurements.

In fig. 1, *A B* represents the surface of a cleavage piece containing a reflecting lamella *E F G H*. The plane of the drawing is perpendicular to the section line of the lamella. The lamella, drawn at an angle ρ of approximately 21°, has the actual position of the main set of lamellæ that cause the aventurization on (001) of the feldspars. The rays are constructed at the approximately true angles obtaining in an oligoclase ($n = 1{\cdot}54$). A very high refractive index ($n = $ about 3) is assumed for the construction of the rays inside the lamella. In the discussions we disregard (as we do in the figures) the double refraction of the feldspar, and also an eventual double refraction of the lamellæ. This will simplify the problems very considerably without changing their general character.

FIG. 2.



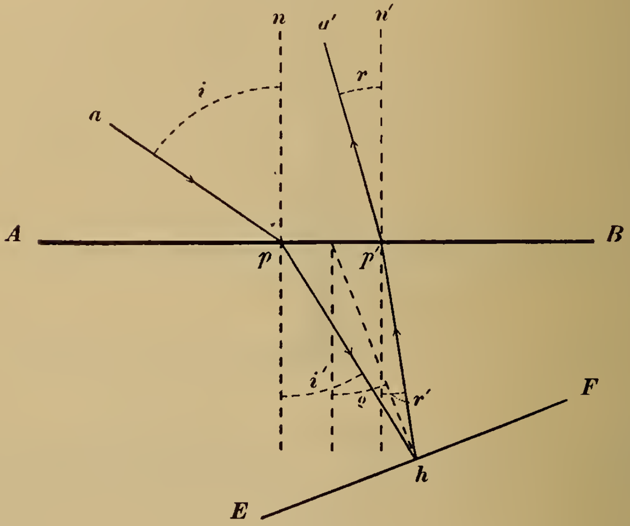
The course of the different rays originating from the incident ray *a p* is shown in fig. 1. It is supposed that the lamella is thin enough to allow a part of the light to penetrate to its lower surface *G H* where one ray *o s* proceeds into the feldspar and the other is reflected in the direction *o k*. There will then be opportunity for an interference between the two rays *h p′* and *k p″* with a path difference equal to *h o k* or approximately the double thickness of the lamella (as the angle *h o k* is always very small). In white light we will, therefore, see interference colors in the direction *p′ a′* (*p″ a″*) of the light rays which pass out through the surface *A B*.

In the following discussion we use the symbol i for the angle *a p n* (fig. 1), the angle of incidence of rays falling on a surface (*AB*) and the symbol r for the angle *a′ p′ n′*, the angle at which the same rays emerge from the same surface after the reflection from the lamellæ.

Fig. 2 shows the relations between the angles i and r for a number of rays constructed on the basis of the same properties as fig. 1. (Feldspar with $n = 1{\cdot}54$; lamellæ with angle $\rho = 21°$.) The angles i and r will differ somewhat for different aventurine feldspars and will especially depend on the angles

ρ. As will be shown further on, however, all the lamellæ that cause aventurization on (001) have practically the same angle ρ_P (about 21°) and those producing aventurization on (010) have an angle ρ_M only a little smaller (around 19°). The differences in the angles i and r will therefore be small. Fig. 2 may then be considered a fair representation of the general relations between the angles i and r in aventurine feldspars where the aventurization is observed on the cleavage faces

FIG. 3.



(001) and (010). The incident rays are marked with small letters and the corresponding reflected rays with the same letters distinguished by prime signs. It is seen that rays $a\ p$ of angle $i = 90°$ are reflected in the direction $p\ a'$ at a very small angle r. For an angle ρ of 21° all the incident and reflected rays fall on the same side of the face normal $p\ n$. For smaller angles ρ they may, in part, fall on opposite sides. The direction $e\ p$ represents the ray which after the refraction at the surface $A\ B$ will coincide with the normal to the reflecting lamellæ. Incident rays along the line $e\ p$ will, therefore, emerge along the same line, that is, the angles i and r for these rays are equal and $e\ p$ represents, in a way, the axis of incidence for the whole reflecting system feldspar-lamellæ. Rays falling on the surface $A\ B$ in any direction between $p\ a'$ and $p\ g$ will not pass out through the same surface after the reflection from the lamellæ, because they will be totally reflected at the surface.

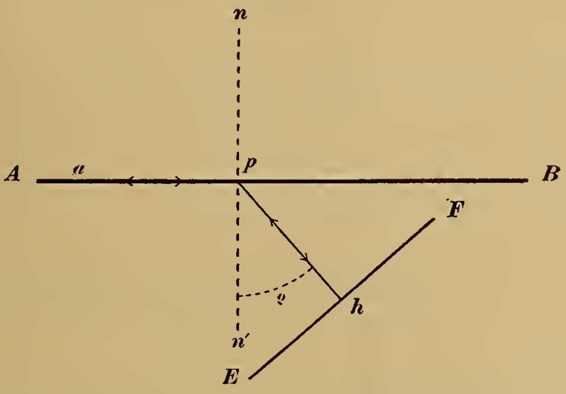
By considering fig. 3 we infer easily how the angle ρ is calculated from the angles i and r of any rays.*

$$\rho = \frac{i' + r'}{2}\,; \quad \sin i' = \frac{\sin i}{n}\,; \quad \sin r' = \frac{\sin r}{n}\,;$$

n is the mean refractive index of the feldspar.

In order that rays falling on a certain surface after the reflection from the lamellæ shall emerge through the same surface, the angle ρ of the lamellæ must not exceed the angle of total reflection for feldspar against air. This is easily seen in fig. 4, which represents a feldspar containing a lamella of angle $\rho = 40°$, approximately the angle of total reflection for oligoclase.

FIG. 4.



For lamellæ parallel to the surface of the feldspar, the reflected rays will, of course, coincide with the rays reflected directly from the surface. Such lamellæ do not, therefore, produce the same brilliant aventurization as lamellæ of medium angles ρ, because the colored light reflected from the lamellæ will be blurred by the white light reflected directly from the surface of the feldspar.

We may now consider a case where the light rays pass in through one face and after the reflection from the lamellæ pass out through another face. In the case illustrated in fig. 5, *AB* and *AC* represent the two cleavage faces (001) and (010) of an oligoclase and *EF* a lamella oriented parallel to $(0\bar{2}1)$; that is

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* See E. Reusch, loc. cit., p. 401, where many of the optical problems are discussed in detail.

the lamella and the two faces of the feldspar lie in the same zone. Rays in the plane perpendicular to the *a*-axis of the feldspar will, therefore, remain in this plane throughout and the calculations of the relations between the different angles are simple. We find easily the following formulæ :

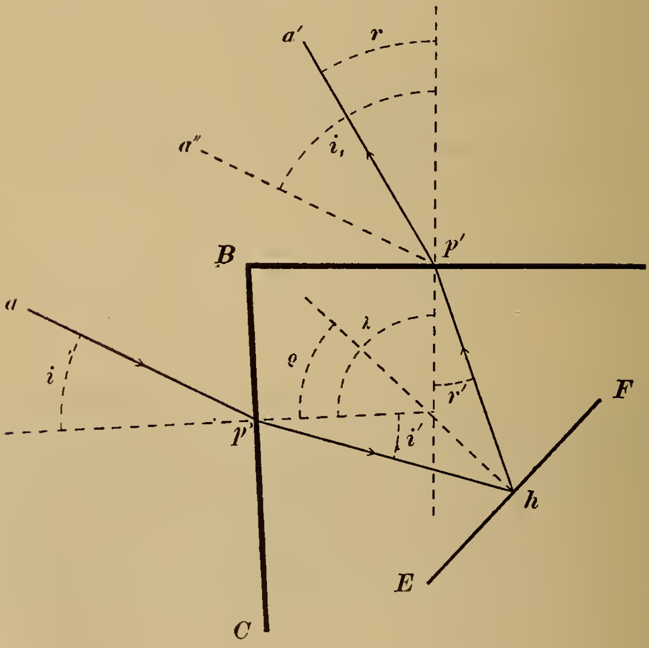
$$\rho = \frac{\lambda + i' - r'}{2}.$$

$$\sin i' = \frac{\sin i}{n} ; \sin r' = \frac{\sin r}{n}$$

$$i = \lambda - i_1$$

The meanings of the different symbols are indicated in fig. 5.

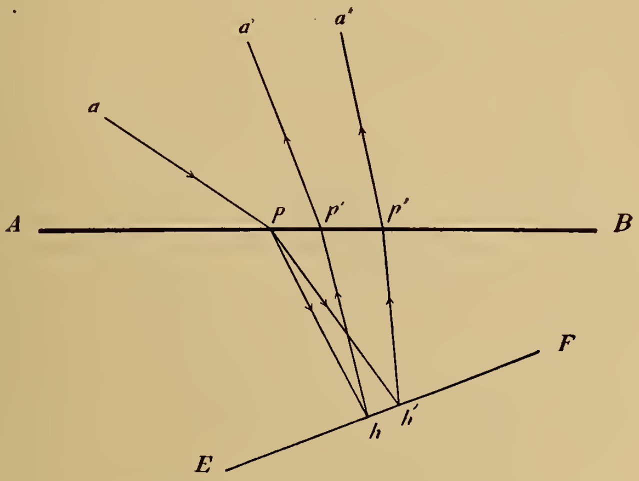
FIG. 5.



These formulæ enable us to calculate the angle ρ of any set of lamellæ lying in the zone of two faces when the angle λ between the faces is known and the angles i (or i_1) and r of any light ray can be measured.

In the preceding discussion we have, in general, tacitly assumed that the light was homogeneous. In fig. 6 the incident ray *a p* is supposed to consist of white light. After the refraction at the surface *A B* the red rays follow the course *p h′ p″ a″* and the violet rays the course *p h p′ a′*. The reflection from the lamellæ of aventurine feldspars will thus, in general, be accompanied by a color dispersion of the light. The magnitude of the dispersion will depend on the angle *i* of the incident rays, the angle ρ of the lamellæ and the specific power of dispersion of the feldspar. As this power of dispersion is low with feldspars the actual color dispersion in aventurine feldspars will always be insignificant. For lamellæ parallel to the surface ($\rho = 0$) there will be no dispersion.

FIG. 6.



Goniometric Measurements.

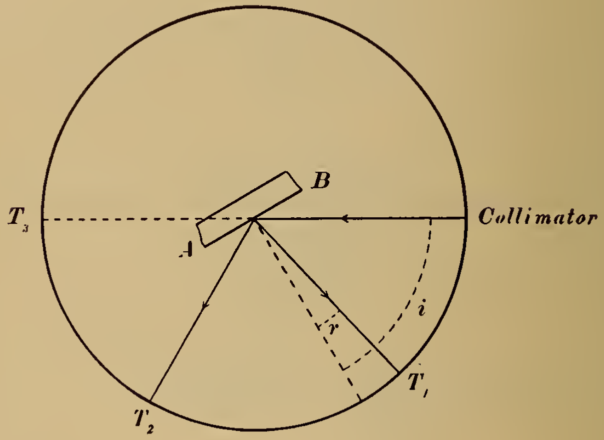
For the goniometric measurements cleavage pieces with smooth faces of the forms (001) and (010) and showing distinct aventurization on both faces were selected. The faces generally measured from 2×2^{mm} to 10×10^{mm}.

The measurements were made with a Goldschmidt two-circle goniometer in the following way: The cleavage face to be used as equator was first adjusted parallel to the vertical circle of the goniometer. The cleavage piece could then be rotated round the horizontal axis without changing the vertical position of the face.

In cleavage pieces composed of polysynthetic twins the single twinning lamellæ were sometimes broad enough for individual adjustment and contained a sufficient number of reflecting lamellæ for measurement. As a rule, however, they were too narrow and the whole set of parallel faces had to be adjusted as one face without regard to the intervening twinning faces. By selecting the broadest set this could be done without difficulty and after the adjustment the signals belonging to the adjusted faces could be easily distinguished from signals belonging to the other twinning faces.

The determination of the angle ϕ of any set of lamellæ that reflected light through the adjusted cleavage face would now

Fig. 7.



consist in measuring the angle between the following two zone axes, both lying in the vertically adjusted face: (1) The zone axis of the two cleavage faces (a-axis). (2) The zone axis of the section lines of the lamellæ. Each zone axis was in turn adjusted parallel to the vertical axis of the goniometer and the position for each read on the vertical circle.

The angles ρ were determined by measuring the angles i and r in the following way: The cleavage piece was adjusted with one face parallel to the vertical circle as before, and the section lines of the set of lamellæ to be measured were set parallel to the vertical axis of the goniometer. The vertical cleavage face was then fixed in a position which gave a suitable angle of incidence to the rays from the collimator and readings were made on the horizontal circle with the telescope in the following three positions (see fig. 7):

(1) T_1, position of reflections from lamellæ. (2) T_2, position of direct reflection from the cleavage face. (3) T_3, position of direct signal from the collimator. How the angles i

and r are computed from the readings is easily seen. The formulæ for the calculation of ρ from i and r have been given before (p. 359).

Direct measurements of the angles ρ could be made occasionally when lamellæ were exposed on fracture faces. These measurements were, of course, in no way different from ordinary goniometric angle measurements.

In determining the angles ρ by measuring the angles i and r we should theoretically obtain two values owing to the double refraction of the feldspar. The deviation between these values is, however, always so small as to be negligible even if a high degree of accuracy were desired. It was, in fact, in most cases, impossible to distinguish two signals in the goniometer telescope.

The color dispersion of the light observed in the same measurements (see p. 361) was also insignificant and it was without noticeable influence on the accuracy of the results when white light was used instead of monochromatic.

The relative accuracy of the goniometric measurements will, of course, depend on the variable qualities of the cleavage faces and the reflecting lamellæ. Owing to the poor cleavage faces after (010) compared with those after (001) (especially in the plagioclases) signals reflected from or passing through (001) were much sharper than signals influenced by (010).

It should be noticed that the error in the determination of an angle ρ is much smaller than the actual errors of measurements of the angles i and r from which ρ is calculated, provided that the refractive index is approximately correct. This is plainly inferred from the formulæ p. 359.

We find that the error in the angle determination in general will increase in the order ρ_P, ρ_M, ϕ_P, ϕ_M. In the best determinations of the angles ρ the probable error of single measurements did not exceed that of ordinary goniometric measurements of medium sharpness ($2' - 3'$). In the poorest determinations of the angles ϕ it would reach 1/2° or more. (See Tables 2–12.)

In most of the measurements the goniometer telescope was used with a reducing attachment; in a few cases with a lense system of low magnifying power. Each angle value listed in the tables (Tables 2–12) is the average of several (generally 5) readings.

Results of Measurements.

The results of the microscopic and goniometric measurements of the planes of orientation may now be briefly summarized.

It was found that the lamellæ, in all the different varieties examined, were oriented parallel to definite, crystallographic faces of the feldspar, and all these faces had rather simple indices. The lamellæ causing the aventurization on the cleavage faces were oriented along the same crystal faces in all the varieties.

Altogether it was found that the planes of orientation of the lamellæ were parallel to faces of the following forms: (112), $(1\bar{1}2)$, $(\bar{1}13)$, (150), $(1\bar{5}0)$, (110), $(1\bar{1}0$, $(0\bar{2}1)$, (010), (001).

Of these (001), (010), (110) and $(1\bar{1}0)$ are known as actual faces in practically all feldspar crystals; $(0\bar{2}1)$ is also a fairly common form, whereas (112), $(1\bar{1}2)$, $(\bar{1}13)$, (150) and $(1\bar{5}0)$ belong to the very rare forms that have been observed only occasionally and with insignificant faces.

Table 1 gives the angles ρ_P, ρ_M, ϕ_P and ϕ_M of the forms mentioned, for albite, anorthite and orthoclase calculated from the known axial ratios of these minerals.*

For the sake of completeness the angles of the forms $(\bar{1}\bar{1}3)$ and (021) are also given. All the angles are given with positive and acute values. The direction in which the angle should be counted and whether the positive or the negative *a*-axis should be used as base is always easily inferred.

For comparison with the measurements the calculated angles of the aventurine plagioclases were simply computed by interpolation between the angles of albite and anorthite on the basis of the known compositions of the plagioclases (see Tables 2–8). This method may not be strictly correct, but it is accurate enough for our purpose and, in fact, probably the most accurate method available,† as the axial ratios of the different plagioclases are but imperfectly known.

The angles measured on microclines (microcline perthites) are compared with the calculated angles of orthoclase for the reason that the microcline, as usual, was always so finely twinned that the orientation of the reflecting lamellæ could not be measured in relation to single twinning lamellæ (as in the case

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*Albite: $a : b : c = 0{\cdot}6367 : 1 : 0{\cdot}5593$
$\alpha = 94° 15'$; $\beta = 116° 37'$; $\gamma = 87° 41'$.
($\lambda = 86° 24'$; $\mu = 63° 28'$; $\nu = 90° 28'$.)

C. Dreyer und V. Goldschmidt, Meddelelser om Grönland, xxxiv, 1907. (In the table of elements, p. 43, is given $\lambda = 86° 42'$ instead of 86° 24'.)

Anorthite: $a : b : c = 0{\cdot}6347 : 1 : 0{\cdot}5501$
$\alpha = 93° 13'$; $\beta = 115° 56'$; $\gamma = 91° 12'$.
($\lambda = 85° 50'$; $\mu = 63° 56'$; $\nu = 87° 6'$).

V. Goldschmidt, Winkeltabellen, (1897, p. 141).

Orthoclase: $a : b : c : = 0{\cdot}6585 : 1 : 0{\cdot}5554$
$\beta = 116° 3'$.

V. Goldschmidt, Winkeltabellen (1897, p. 143).

† See V. Goldschmidt, Winkeltabellen (1897, p. 404).

TABLE 1

Form	ALBITE				ANORTHITE				ORTHOCLASE			
	Pole : Normal to 001		Pole : Normal to 010		Pole : Normal to 001		Pole : Normal to 010		Pole : Normal to 001		Pole : Normal to 010	
	ρ_P	ϕ_P	ρ_M	ϕ_M	ρ_P	ϕ_P	ρ_M	ϕ_M	ρ_P	ϕ_P	ρ_M	ϕ_M
112	20° 38′	59° 10′	76° 10′	18° 10′	21° 3′	56° 45′	74° 41′	18° 8′	20° 57′	56° 38′	78° 40′	17° 44′
$1\bar{1}2$	21 51	55 52	81 21	18 10	21 16	58 27	83 1	18 8				
$\bar{1}13$	19 44	55 52	75 38	16 46	18 57	58 27	76 13	16 34	19 2	56 38	79 40	16 4
$\bar{1}\bar{1}3$	19 30	59 10	83 36	16 46	19 47	56 45	83 18	16 34				
021	43 13	0 0	43 11	0 0	42 38	0 0	43 12	0 0	44 56	0 0	45 4	0 0
$0\bar{2}1$	46 49	0 0	46 47	0 0	46 46	0 0	47 24	0 0				
110	65 8	59 10	60 38	63 23	65 53	56 45	58 4	64 4	67 47	56 38	59 23	63 57
$1\bar{1}0$	69 10	55 52	59 56	63 23	69 20	58 27	62 27	64 4				
150	78 2	17 38	19 21	63 23	79 58	17 23	19 58	64 4	81 55	16 54	18 41	63 57
$1\bar{5}0$	84 57	17 13	19 15	63 23	84 21	17 36	19 32	64 4				

Fig. 8.

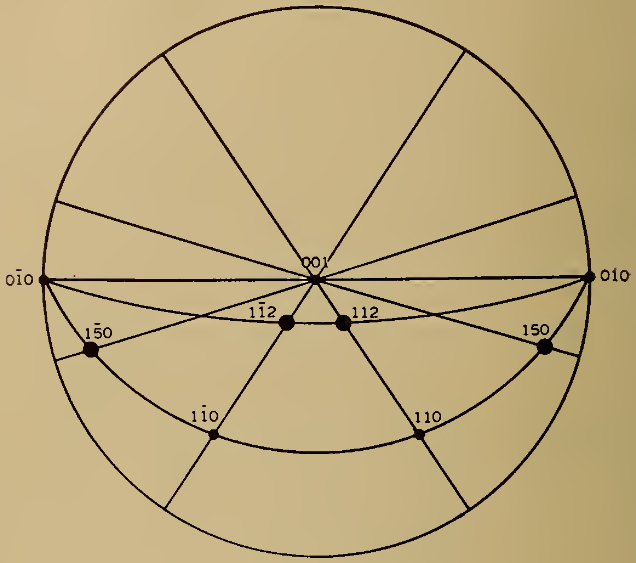

001
01̄0
010
11̄2
112
15̄0
150
11̄0
110

Fig. 9.

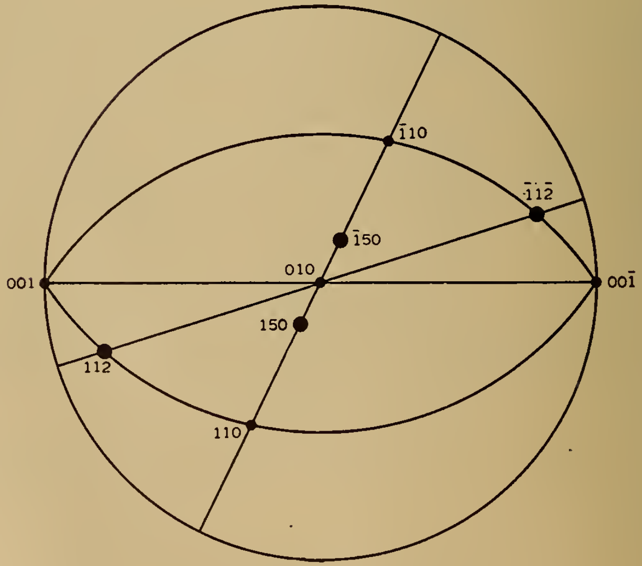

1̄10
1̄1̄2
1̄50
010
001
001̄
150
112
110

FIG. 10.

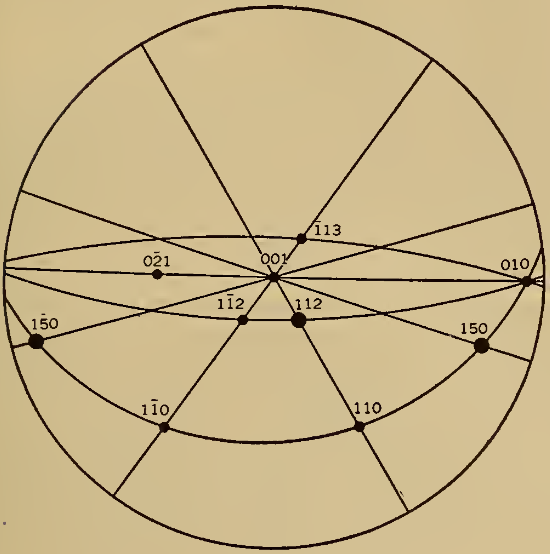
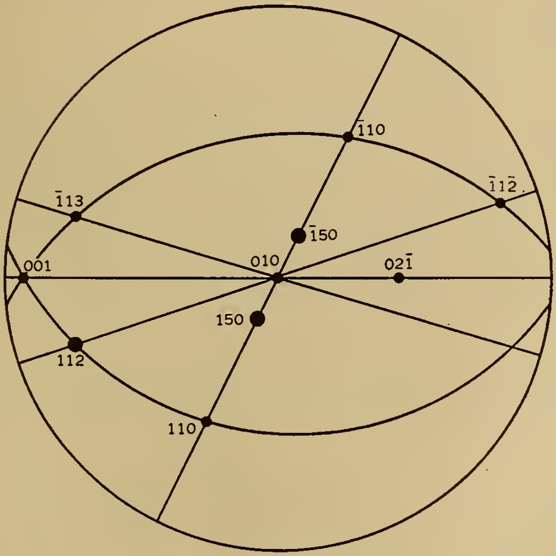

$\bar{1}13$
$0\bar{2}1$
001
010
$1\bar{1}2$
112
$1\bar{5}0$
150
$1\bar{1}0$
110

FIG. 11.


$\bar{1}10$
$\bar{1}1\bar{2}$
$\bar{1}13$
$\bar{1}50$
001
010
$02\bar{1}$
150
112
110

of the plagioclases), but could only be referred to the apparently monoclinic elements of the entire twinned cleavage pieces. Moreover, the difference in angles between orthoclase and microcline is insignificant.

The faces representing the planes of orientation of the reflecting lamellæ are plotted in stereographic projections in figs. 8–11. Figs. 8 and 9 show the faces observed in microclines and figs. 10 and 11 those observed in plagioclases. In figs. 8 and 10 the plane of projection is (001), in figs. 9 and 11 it is (010). The most important planes of orientation are marked with large dots; the less important with smaller dots.

The most numerous lamellæ are those which produce the aventurization on the cleavage faces. In the plagioclases the aventurization on (001) is chiefly caused by lamellæ after (112) and to a less extent by lamellæ after $(1\bar{1}2)$. In the microclines these two forms are equal. The aventurization on (010) is always caused by lamellæ after (150) and $(1\bar{5}0)$, both of about equal development, in plagioclases as well as in microclines. Sometimes we observe numerous lamellæ parallel to one or both of the cleavage faces (001) and (010), but as a rule these faces contain very few lamellæ and often none. The same holds true for the faces (110) and $(1\bar{1}0)$. Parallel to $(0\bar{2}1)$ there were seen a few lamellæ in two of the plagioclase varieties examined. Lamellæ parallel to $(\bar{1}13)$ were only observed once, also on a plagioclase.

Orientation of the Edges of the Lamellæ.

In cases where the lamellæ showed definite crystal outlines it was plainly seen that there were certain directions along which the edges were more frequently oriented than along others. This orientation was, however, not so regular as the orientation along the planes. Simple crystallographic relations of the directions of the edges were only found exceptionally. The angles varied considerably even on the same specimen, and on different specimens the orientation was often quite different.

It should be emphasized that we do not know the crystallographic relation between any of the edges and the crystal axes of the lamellæ, even if we take it for granted that the lamellæ are hematite crystals. In the six-sided lamellæ, for instance, we have no means of deciding whether the edges are formed by faces of the first or the second order; and in the distorted lamellæ with eight- or ten-sided outlines the identification of the edges is still more uncertain. Moreover, many of the lamellæ have no regular outlines. We are, therefore, in general not in a position to establish the mutual orientation between the crystal axes of the feldspar and those of the lamellæ.

In view of these facts, it was of minor interest to undertake extensive measurements of the orientation of the edges. Measurements were only made, on sections after (001) and (010) of the angles between the a-axis (cleavage lines) of the feldspar and the projections of the edges of the lamellæ on the respective cleavage face. These measurements can be most conveniently included in the special descriptions of the specimens.

THE PROPERTIES OF THE REFLECTING LAMELLÆ.

The lamellæ were too thin to be separated mechanically from the feldspar. They were, therefore, chiefly studied under the microscope in cleavage pieces or sections of the feldspar.

The different aventurine feldspars showed considerable variations as to shape and size of the lamellæ, but no distinction between different varieties could be made on the basis of other qualities. There is, therefore, no reason to consider that the lamellæ consist of more than one mineral species. In the following descriptions we refer to the general qualities of lamellæ from all the specimens examined.

Size; crystal outlines.

The smallest lamellæ were hardly visible under the microscope; the largest could be easily seen with unaided eye. Between these there were all transitions. The lamellæ of the microcline were generally smaller than those of the plagioclase, the former seldom measuring more than $0{\cdot}2^{mm}$ in diameter, the latter often measuring as much as 3^{mm}.

As observed by Scheerer[*] and others who studied aventurine feldspars under the microscope, the lamellæ sometimes form nearly regular hexagons but more often they show distorted, six-sided or rhomb-shaped outlines. Unsymmetrical eight- or ten-sided outlines are also often seen, and narrow rectilinear strips several times as long as wide are very common. Lamellæ with rounded or irregularly curved outlines are frequently observed. When parallel to one of the cleavage faces the lamellæ often showed more regular hexagonal or rhombic outlines than in other positions (see Plates I–III).

Interference colors; thickness.

The intense colors displayed by most of the lamellæ in reflected light were explained by Sheerer[†] as colors of thin films. The correctness of this explanation could be readily proved in the course of the present microscopic study. The

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[*] Loc. cit., p. 156.

[†] Loc. cit., p. 157.

light reflected from the opaque lamellæ was always of the same grayish color, whereas the reflections from the transparent lamellæ showed vivid colors varying with the absorption colors, that is, with the thickness of the lamellæ. It was, for instance, observed that the absorption colors of some lamellæ changed gradually from very light yellow near the edges to light brown red towards the middle. The interference colors in reflected light changed in the same lamellæ from dark gray of first order at the edges to the brilliant colors of second order near the middle.

In the thin lamellæ of yellowish or light brown tints (in transmitted light) the interference colors were not noticeably modified by the absorption of the one of the interfering rays that passed through the lamellæ. As the lamellæ became thicker, however, the influence of the absorption was more pronounced and in the deep brown red lamellæ the absorption was so strong as to suppress the interference colors. The reflected light of these lamellæ was therefore grayish like that of the opaque lamellæ.

We know that the thickness of the lamellæ is about 1/2 of the path difference between the interfering rays reflected from them. It is obvious, then, how the thickness of the thinner lamellæ that show distinct interference colors can be approximately determined. The very thinnest of the lamellæ showed the interference colors gray and white of first order and their thickness could accordingly be estimated at from 50 to 100 $\mu\mu$. Thicker lamellæ showed interference colors from yellow of first to red of second order corresponding to thickness of from 150 to 500 $\mu\mu$. The majority of lamellæ had a thickness of between 100 and 400 $\mu\mu$. In sections where the lamellæ were cut approximately perpendicular to their planes they appeared as almost invisible streaks entirely too thin to be measured with the ordinary devices of the microscope.

During the observation of the interference colors it was noticed that light reflected from lamellæ with small angles ρ never showed any detectable polarization.

Absorption colors.

The color of the reflecting lamellæ in transmitted light varied with their thickness from very light yellow and reddish brown to deep brown red or blood red.

Lamellæ forming small angles ρ with the plane of the section showed no pleochroism. Lamellæ of large angles ρ, on the other hand, appeared at first sight to be strongly pleochroic. In ordinary thin sections of the feldspar we observe the following absorption colors of such lamellæ (e. g. lamellæ parallel to (112) seen in sections after (010) or lamellæ parallel to (150) in sections after (001)): (1) In vibration directions perpendicular to the section lines of the lamellæ—colors varying from yellow to strong brown red or blood red (depending on the thickness of the lamellæ). (2) In vibration directions parallel to the section lines of the lamellæ—colors dark brown of nearly the same tinge in all lamellæ (independent of their thickness). The change is thus apparently stronger in the thinner than in the thicker lamellæ. There is no distinct change in the quality of the colors but rather a change in the tints of the same brownish color from dark in one direction to light in the other.

This change in tints has been observed by previous authors and explained as pleochroism.* As the reflecting lamellæ have been considered hematite in tabular crystals after the base a strong pleochroism $\omega > \epsilon$ (ω dark brown, ϵ light brown) has been generally adopted as one of the characteristic qualities of hematite. A somewhat closer consideration of the observations described will, however, show that this explanation is not correct.

If the lamellæ are hematite crystals in plates after the base, those parallel to the surface of the feldspar section, or forming small angles (ρ) with the same, must show the absorption color of the vibration direction ω. According to the observations on such lamellæ their absorption colors vary between yellow and brown red. According to the observations on lamellæ of large angles ρ, on the other hand, the color of the vibration direction ω (direction parallel to the section lines of the lamellæ) should be dark brown with very little variation, whereas the colors of ϵ (or strictly a direction between ϵ and ω) should vary between yellow and brown red. In other words the absorption colors of ω in the lamellæ with small angles ρ correspond to the colors of ϵ in the lamellæ with large angles ρ. This indicates that the lamellæ have only a weak pleochroism, if any, and the dark absorption colors for vibration directions parallel to the section lines of the lamellæ of large angles ρ must be explained in the manner outlined below.

Fig. 12 shows the light rays passing through a cleavage piece $A\ B\ C\ D$ containing a lamella $E\ F\ G\ H$ of angle $\rho = 75°$. The light of the incident ray $a\ p\ h$ is supposed to be unpolarized. By the influence of the lamella the refracted and reflected rays become polarized† with the reflected ray $h\ p'\ a'$

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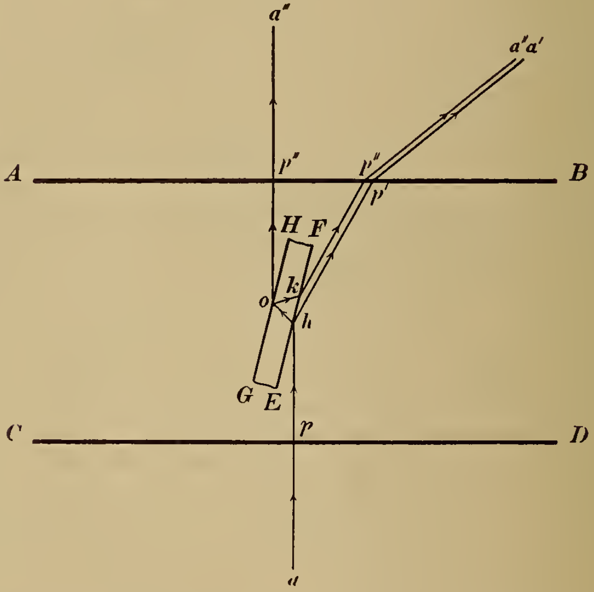
* F. Rinne, Neues Jahrb. Min., 1890, i, p. 183.

† The phenomenon of polarization by reflection and refraction is too well-known to need any explanation. It may only be recalled that the polarization, in the case of metallic substances like the lamellæ here considered, is never complete either in the reflected or in the refracted ray, but reaches a maximum for a certain (always large) angle, the main angle of incidence, and becomes insignificant for small angles of incidence. C. Försterling (Neues Jahrb. Min., B. B., xxv, 360, 1908) determined the main angle of incidence for hematite at 71°–73° for rays of medium wave lengths.

vibrating perpendicular to the plane of incidence and the transmitted ray $o\,p'''\,a'''$ vibrating in the same plane. Now if the incident ray $(a\,p)$, therefore, consists of polarized light the transmitted ray $(p'''\,a''')$ will have its maximum of intensity for the vibration direction perpendicular to the section line of the lamella and the minimum for the direction parallel to this line. This is exactly the apparent pleochroism $(\omega > \epsilon)$ observed on lamellæ of large angles ρ.

The correctness of the above explanation was proved by the fact that the light reflected from lamellæ of large angles ρ

Fig. 12.

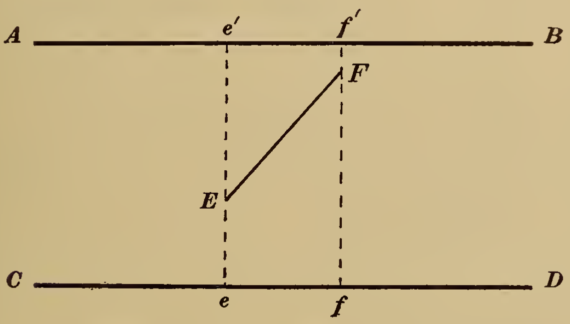


(rays $p'\,a'$, fig. 12) was found to be strongly polarized with vibration direction parallel to the section lines of the lamellæ. This was observed in a number of sections with lamellæ of angles ρ around 75°. It is then a necessary conclusion that the transmitted rays $(p'''\,a''')$ must be polarized with vibration direction perpendicular to the section lines.

The apparent pleochroism in the lamellæ of aventurine feldspars when observed at large angles ρ is not, therefore, due to any strong difference in absorption between the vibration directions ω and ϵ (if we suppose that the lamellæ consist of hematite tables), but is explained, as outlined above, by the polarization of rays when they fall on the lamellæ at the appropriate angles of incidence.

In thick sections or cleavage pieces the lamellæ of large angles ρ show in polarized light (with only one nicol) distinct interference spectra with bands parallel to the section lines. These lamellæ show the same apparent pleochroism as those in thin sections. The thicker the part of the feldspar penetrated by the lamellæ the larger is the number of bands in the spectra. In lamellæ penetrating only a thin part of the section we see, as in ordinary thin sections, no extended spectra but sometimes single, colored stripes. By rotating the microscope stage all spectra disappear in two positions at right angles with each other coinciding with the extinction directions of the feldspar between crossed nicols. This phenomenon is explained by the fact that the lamellæ (of large angles ρ) are included in the doubly refracting feldspar. In fig. 13 EF

FIG. 13.



indicates a lamella included in a feldspar section $A\ B\ C\ D$ at an angle ρ large enough to make the rays transmitted through it become noticeably polarized. If we use the lower nicol of the microscope the lamella will form a somewhat imperfect analyzer for the wedge-shaped part of $E\,F\,f\,e$ of the feldspar that lies below it. If we use the upper nicol the lamella will be polarizer for the wedge-shaped part $E\,F\,f'\,e'$ of the feldspar that lies above it. In either case we shall obtain an interference spectrum corresponding to the part of the feldspar wedge that lies between the lamella and the surface of the section, (the lower surface in one case, the upper in the other). It is obvious that the bands of the spectra must always be parallel to the section lines of the lamellæ. In such a stauroscopic system, where one of the nicols is replaced by lamellæ included in the section to be observed, we can not change the angles between the "nicols" and at the same time the relative position between the vibration directions of the "nicols" and those of the section at will. If the "nicols" are crossed the feldspar section may not be in a favorable position for showing interference colors and when the feldspar is in the most favorable position the vibration directions of the "nicols" may form only a small angle with each other. Remembering this the behavior of lamellæ of large angles ρ on rotating the microscope stage presents no difficulty.

Double Refraction.

Lamellæ parallel to (or forming small angles ρ with) the sections extinguished simultaneously with the feldspar between crossed nicols. Lamellæ of large angles ρ, on the other hand, remained light when the feldspar extinguished and thus proved to be anisotropic. This is the relation to be expected if we consider the lamellæ uniaxial crystals in plates after the base. Attempts to discover axial figures in the isotropic lamellæ failed, but this is not surprising when we remember the extreme thinness of the lamellæ, most of which were actually no thicker than about 1/100 of the thinnest rock sections (see p. 370), and also consider the disturbing influence of the birefringent feldspar in which the lamellæ were enclosed.

The course of the rays through lamellæ showing double refraction is seen in fig. 12 ($a\ p\ h\ o\ p'''\ a'''$). The rays are never transmitted through the lamellæ in a direction near the plane of the lamellæ. If the lamellæ are considered to be hematite or other uniaxial crystals in basal plates, we see that the transmitted rays will never have the vibration direction ϵ. Consequently we shall in no case obtain the maximum double refraction and the path difference of the transmitted rays will depend on the thickness of the lamellæ and on their angle with the section (angle ρ).

Chemical Tests.

Scheerer* found that the originally red powder of sunstone from Tvedestrand turned white on heating with hydrochloric acid, the filtrate containing iron oxide. In the course of the present study similar tests were made on samples of various aventurine feldspars with the same result. Microscopic examinations of the powder showed that the red (pink) color was due to the presence of the thin reflecting lamellæ described and the discoloring by treatment with HCl was due to the solution of these lamellæ. These tests, therefore, show that the lamellæ of the aventurine feldspars contain iron oxide.

* Pogg. Ann., lxiv, 160, 1845.

Some Observations on Hematite.

For comparison with the reflecting lamellæ of aventurine feldspar several samples of hematite were examined as to transparency, absorption colors and pleochroism. Fine powder of the samples was imbedded in liquid Canada balsam and examined under the microscope. The degree of transparency could be estimated by selecting tabular grains lying on the flat surface, noting the color and then tilting the grains on edge (by moving the cover glass) for measurement of the thickness. The transparency varies within wide limits, some hematites being practically opaque even in the finest powder, others being transparent. For a sample of medium transparency (micaceous hematite from Montgomery County, Pa.) the following observations were made:

Absorption color	Thickness
Perfectly opaque	0·01 ^{mm}
Very dark blood red, almost opaque	0·003^{mm}
Deep blood red	0·001^{mm}

Grains of various orientation were seen in the sections. Some were parallel to the base and were perfectly isotropic; others were oriented at angles with the base and showed a strong double refraction with definite extinction directions.

If the hematite possessed a strong pleochroism this should be observed in the grains showing double refraction. In spite of careful observation, however, no distinct change in color or tint could be seen in any of the grains examined. We, therefore, conclude that the hematite has little or no pleochroism.

The absorption colors of the transparent varieties of hematite are very characteristic, blood red, brown, red, etc., according to variety and thickness and are distinctly different from those of goethite, which are much lighter and always a purer brown or yellowish.

It will be seen that these properties of hematite agree well with the corresponding properties of the reflecting lamellæ of aventurine feldspars.

Summary of the Properties of the Lamellæ.

We may now summarize the data bearing on the identification of the reflecting lamellæ.

(1) The hexagonal outlines often shown by the lamellæ, taken in connection with the optical properties which agree with uniaxial crystals in plates after the base, point to a hexagonal or trigonal symmetry.

(2) The absorption colors are the same in the lamellæ as in hematite and the lack of distinct pleochroism is also characteristic for both.

(3) Chemical tests show that the lamellæ contain iron oxide.*

(4) Thermal experiments (to be described below) show that the lamellæ do not undergo any essential change even by a prolonged heating of the aventurine feldspar at temperatures around 1050°. If the lamellæ consisted of goethite or other hydrated iron oxides we should expect a considerable change due to the decomposition of such hydrates by heating.

All these data lead to the conclusion that the reflecting lamellæ of the aventurine feldspars consist of hematite in tabular crystals after the base, as first suggested by Scheerer.

THERMAL DATA.

In order to obtain, if possible, some information on the stability relations between the feldspar and the hematite inclusions, a number of heating experiments were carried out.† Fresh, transparent cleavage pieces containing hematite lamellæ of various size and thickness were selected for the experiments. The outlines of the cleavage pieces and their included lamellæ were drawn with camera lucida and the colors of the different lamellæ in transmitted light were noted. After appropriate heating (in the electric resistance furnace) the cleavage pieces were removed to the air, examined under the microscope and compared with the drawings.

A brief record of the experiments is given below.

(1) Cleavage piece with numerous transparent hematite lamellæ heated for one hour at 1260°: The feldspar remained birefringent throughout with outlines sharp as before the heating; colorless; transparent, but somewhat dim. All hematite inclusions disappeared.

(2) Cleavage piece with few light-colored hematite lamellæ of sharp outlines heated for one hour at 1150°: No visible change.

(3) Same piece heated for one-half hour at 1200°: No change.

(4) Same piece heated for one-half hour at 1230°: Feldspar unchanged. Some hematite lamellæ disappeared; others became lighter and were corroded at the edges.

(5) Piece from exp. (1) heated for twenty-four hours at about 1050°: Feldspar milk white, dull, full of very fine black dust.

(6) Cleavage piece with numerous hematite lamellæ heated for one-half hour at 1235°: Feldspar birefringent; colorless; somewhat dim, but still transparent. All hematite disappeared.

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* In this connection it should be noticed that lamellæ of similar qualities forming inclusions in carnallite have been analyzed separately and found to consist of Fe_2O_3 without H_2O (O. Ruff, "Kali", i, 81, 1907).

† Specimens from Aamland, Söndeled, Norway, yielded the most favorable material for these experiments on account of the freshness of the feldspar and the large size of the hematite lamellæ.

(7) Cleavage piece with some transparent and some opaque lamellæ heated for one hour at 1230°: Feldspar practically unchanged. Nearly all hematite lamellæ disappeared.

(8) Piece from exp. (7) heated for eighteen hours at about 1050°: Feldspar white, dull, only little transparent. The opaque lamellæ reappeared in the same positions and with the same outlines as before the heating (of exp. 7). They did not reflect the light as before, however, and were evidently made up of a fine aggregate of an opaque or very dark brown substance. The originally transparent lamellæ did not reappear, but at the places they had occupied a dense crowding of black dust was seen.

(9) Piece from exp. (8) heated for one hour at 1235°: The opaque lamellæ again disappeared.

(10) Same piece heated for 40 hours at about 1050°: Opaque lamellæ reappeared as in exp. (8). The feldspar opaque, full of black dust.

(11) Cleavage piece with opaque and transparent lamellæ heated for one hour at 1235°: Feldspar practically unchanged, only a little dim. Both the opaque and the transparent hematite lamellæ disappeared.

(12) Same piece heated for 45 hours at about 1050°: Feldspar dim and full of black dust. Opaque lamellæ reappeared in the same positions as before. The substance of the lamellæ now a dark aggregate as in exp. (8).

(13) Cleavage piece with opaque and transparent hematite heated for 22 days at about 1050°. The piece was examined and replaced after 1, 2, 7 and 14 days of heating. After 1 day some of the opaque lamellæ had become transparent with a deep brown color; others remained opaque. The originally transparent lamellæ were apparently unchanged. After 2 days no further change visible. After 7 and 14 days all lamellæ had become visibly lighter, some of the originally opaque lamellæ now being reddish brown, others being deep red. After 22 days the same relations persisted. The feldspar remained perfectly clear throughout (without formation of dark dust as in the cases where the heating had been first carried up to 1230°–1260°). The reflections from the lamellæ were just as intense as before the heating.

The result of these experiments may be summarized as follows:

By heating fresh cleavage pieces of aventurine feldspar at temperatures below 1230° (around 1050°) the hematite lamellæ undergo a slow change. The opaque lamellæ become more or less transparent and the transparent ones generally grow a little lighter. The change from opaque to transparent with brown red color seems to take place rather quickly, whereas the change from darker to lighter brown red or to yellowish brown is very slow and in the lightest lamellæ a change is hardly detectible, even after a long heating. The opaque lamellæ are seldom homogeneous, but generally contain a number of irregular spots of transparent substance which shows the same colors as the entirely transparent hematite lamellæ. By a short heating these transparent parts undergo practically no change while the opaque parts become transparent and soon acquire the same color as the transparent parts so that the lamellæ become homogeneous. It seems as if the changes take place with retarded velocity and gradually cease when a certain stage is reached.

These changes might be explained as being due to a direct solution of the hematite into the feldspar (in the solid state) whereby the hematite lamellæ grew thinner and lighter. In that case we should expect the most conspicuous change in the thinnest lamellæ, some of which ought to disappear if the heating were continued for a sufficiently long time. As the experiments show, however, the thinnest lamellæ were evidently the most persistent ones, none of them disappearing and most of them undergoing no visible change even after 22 days' heating.

The change may be explained by assuming that there is a transition from a darker to a lighter modification of the hematite. The darker form is perhaps a secondary product and the original, lighter form is restored by heating. An explanation of this nature seems to account for the actual behavior of the different hematite lamellæ on heating. As the experimental data are few and only suggestive we have no basis for a detailed discussion of these problems.

The sudden disappearance of the hematite lamellæ at 1235° is most reasonably interpreted as due to a simultaneous melting of hematite together with a portion of the feldspar surrounding it; perhaps a eutectic melting or possibly a melting with a reaction between the feldspar and the hematite. Owing to the extreme thinness of the lamellæ the amount of feldspar necessary for such a melting must in any case be small. The liquid (glass) resulting from the melting will therefore occupy only very thin films in the place of the lamellæ and will escape detection under the microscope. It will look as if the lamellæ disappeared without leaving any trace, while the surrounding feldspar was unchanged and showed no sign of melting. The fact that the opaque lamellæ reappear in the same places by heating at a lower temperature proves that their substance can not have travelled far. The substance of these reappearing lamellæ is evidently different from that of the original lamellæ, and the iron oxide must therefore have undergone some change by the melting and recrystallization. We have no means of deciding of what nature this change may have been. It is not unlikely, however, that at least a part of the hematite in melting has been reduced to magnetite.

ORIGIN OF THE HEMATITE LAMELLÆ.

The investigations above described show that the aventurine feldspars must be considered oriented intergrowths between feldspar and hematite. The essential features of the intergrowths are these: The hematite crystals form exceedingly thin plates after the base and the plates are oriented parallel to some simple crystal faces of the feldspar with the edges of the hematite crystals also, in general, definitely oriented. These facts should be borne in mind when we seek an adequate explanation of the origin of the hematite lamellæ.

Of the different possible theories there are two that seem to account well for the oriented intergrowth, viz.: The theory of simultaneous crystallization suggested by Scheerer and the theory of unmixing in the solid state intimated by Johnsen (see review of literature). In discussing the origin of the hematite lamellæ in carnellite and cancrinite Johnsen points out the reasons for preferring the theory of unmixing to the theory of simultaneous crystallization in the cases of the two minerals mentioned. Similar reasons are evidently valid also for the aventurine feldspars.

It is obvious that the planes of growth of the feldspar have not, in general, coincided with the principal planes of orientation of the hematite lamellæ, as the latter planes represent extremely rare forms with the feldspars. It is highly probable, for example, that the faces 112 and 150 have never existed as crystal faces (faces of growth) in any of the specimens considered, and still they are the most important planes of orientation of the lamellæ in all aventurine feldspars. If the aventurine feldspars were considered products of simultaneous crystallization of feldspar and hematite, therefore, we would have to assume that the majority of the extremely thin hematite lamellæ during their growth formed angles with the principal faces of growth of the feldspars. This is improbable according to the common experience with crystal intergrowths, and the orientation of the hematite lamellæ thus forms a strong objection against the theory of simultaneous crystallization; a theory which otherwise would seem very reasonable.

The formation of aventurine feldspars by unmixing in the solid state may be conceived as follows: The feldspar crystals were, at the time of their separation, wholly or in part homogeneous and contained small amounts of Fe_2O_3 in solid solution, either as hematite or as a constituent of a ferric compound. By a change in the exterior conditions prevailing at the time of formation, e. g. change in temperature, the equilibrium of the solid solution may be disturbed in such a way that Fe_2O_3 can no longer be held in solution, but must separate in individual crystals. The hematite molecules will then move towards the centers of crystallization (that is the locations of the hematite lamellæ) and feldspar molecules must move in the opposite directions. From the extreme thinness of the lamellæ we conclude that practically all these movements have taken place in the planes of orientation of the lamellæ. These planes, therefore, seem to represent definite structural planes in the feldspar, perhaps translation planes,* along which the molecules can move relatively easily. In such planes there will again be certain directions, translation directions,* of maximum mobility of the molecules, and these may account for the distortions of the hematite lamellæ. It should be noticed that some of the planes of orientation actually are important structure planes of the feldspar. Thus (001) and (010) are both cleavage planes and twinning planes. Of (110) and $(1\bar{1}0)$ one or both are cleavage planes and $(0\bar{2}1)$, is a twinning plane. It is, therefore, reasonable to consider the other planes of orientation, especially (112), $(1\bar{1}2)$, (150) and $(1\bar{5}0)$, which are observed in all aventurine feldspars, as definite structural planes, planes of translation, as suggested.

We may summarize the conclusions as to the origin of the hematite lamellæ as follows: The aventurine feldspars have been formed by unmixing of an originally homogeneous solid solution of the feldspar and hematite (or a ferric compound) in such a manner that thin hematite lamellæ have separated along structural planes (translation planes) of the feldspar.

II. DESCRIPTION OF THE SPECIMENS.

The present section contains brief descriptions, including tabulations of measurements, of all the specimens examined.

The optical properties of the feldspars were only determined to the extent necessary for an identification of the species.† Extinction angles on (001) and (010) were determined on thin sections or cleavage pieces. Refractive indices were determined on powdered material by the immersion method. As a rule only approximate determinations of the mean refractive index β were made in white light. Exceptionally the refractive

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* See A. Johnsen, Fortschritte der Mineralogie, vol. iii, p. 93, 1913.

† The graphical plot devised by F. E. Wright, this Journal (4), xxxvi, 540, 1913, was used in the determinations of the plagioclase.

index of the feldspar glass, produced by melting the powdered feldspar, was determined.[*]

In the descriptions of the hematite lamellæ only the features most characteristic for each specimen are given. Qualities like thickness, absorption colors, etc., have already been described, and as they were practically the same for all varieties they will be mentioned only exceptionally in the following descriptions.

Albite from Fisher Hill Mine, Mineville, Essex County, New York.[†]

The feldspar.—The cleavage pieces were rather fresh, transparent, of a strong red color, with patches of a green substance not identified.

Extinction angle on (001) = + 3°
" " " (010) = +18°
$\beta = 1{\cdot}535$
Composition: $Ab_{92}An_{8}$, a comparatively pure albite.

Polysynthetic twinning after the albite law with the one set of lamellæ comparatively broad and the other very narrow. The twinning striation on (001) was accordingly very fine.

The hematite lamellæ.—The aventurization was rather subdued, silky, produced by a great number of very small lamellæ.

Most of the lamellæ form very narrow, linear strips of maximal dimensions $0{\cdot}3 \times 0{\cdot}01^{mm}$; some form larger flakes with more equal diameters (maximum $0{\cdot}3^{mm}$). The narrow lamellæ are generally irregularly rounded at the ends, seldom showing edges that indicate six-sided outlines. The larger flakes are sometimes approximately hexagonal, but more often irregularly rounded or tongued. Figs. 1 and 2, Pl. I show the most characteristic shape of the lamellæ.

Orientation of the lamellæ.—The goniometric measurements are given in Table 2. The planes of orientation were: (001), (010), (112), $(1\bar{1}2)$, $(0\bar{2}1)$, (150), $(1\bar{5}0)$. Most prominent were (112), (150), and $(1\bar{5}0)$, all of which contained numerous lamellæ. After (010) there were also many lamellæ, often larger than the others; after (001), $(1\bar{1}2)$ and $(0\bar{2}1)$ there were few.

The lamellæ after (112) and $(1\bar{1}2)$ were generally oriented with the projections of the elongated edges on (001) parallel to the *a*-axis. Most of these lamellæ were of the type of narrow strips described above. Other lamellæ after (112) were oriented with the projections of their elongated edges on (001)

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[*] This method for determining plagioclase feldspars is very convenient, when a high temperature furnace is available, and probably as accurate as the best of the other optical methods. See E. S. Larsen, this Journal (4), xxviii, 265, 1909.

[‡] Specimens from U. S. National Museum, No. 47773.

TABLE 2

$Ab_{92}An_8$; $n = 1·535$

Form	Measured		ρ		ϕ	
	i	r	Calculated from measurements	Calculated from axial ratios	Measured	Calculated from axial ratios
Pole : Normal to 001 (ρ_P and ϕ_P)						
112	62° 18′	10° 21′	20° 58′	20° 39′	58° 30′	59° 0′
	62 50	10 10	21 0		57 22	
112	62 43	12 14	21 40	21 49	56 30	56 3
	62 52	12 22	21 43		57 0	
$0\bar{2}1$	[1]66 52	27 24	46 23	46 49	0 0	0 0
Pole: Normal to 010 (ρ_M and ϕ_M)						
150	44 54	17 15	19 16	19 24	63 24	63 26
$1\bar{5}0$	45 7	16 35	19 6	19 16	64 22	

[1] $\lambda = 93° 24'$.

forming +53° or +63° with the *a*-axis. They formed comparatively broad strips and penetrated a number of the twinning lamellæ of the feldspar. Lamellæ after $(0\bar{2}1)$ were often oriented with their elongated edges approximately parallel to the *a*-axis. Most of the lamellæ after (150) and $(1\bar{5}0)$ formed narrow linear strips parallel to the *c*-axis; the angle between these strips and the *a*-axis was measured at about 63·5°. The lamellæ after (010) formed the larger flakes observed in sections after (010).

Albite from near Media, Delaware County, Pennsylvania.[*]

The feldspar.—The cleavage pieces were fresh, transparent, grayish or colorless.

Extinction angle on (001) = + 1°
" " " (010) = + 16°
$\beta = 1·535$
Composition : $Ab_{91}An_9$, albite.

The feldspar consisted of single individuals, sometimes without any twinning but generally with very narrow twinning lamellæ after the albite law inserted at regular intervals.

[*] Specimens from U. S. National Museum, No. 79828.

The hematite lamellæ.—Large portions of the feldspar were perfectly free from lamellæ; others contained many and showed a strong aventurization.

Most of the lamellæ were elongated, often without regular terminal edges. Sometimes they were also approximately six-sided or rhomb-shaped. They were very small, seldom more than 0·2 × 0·1$^{\text{mm}}$.

Orientation of the lamellæ.—The goniometric measurements are given in Table 3. The forms observed as planes of orientation were: (001), (010), (112), $(1\bar{1}2)$, (150), $(1\bar{5}0)$. Of these the cleavage faces (001) and (010) contained very few lamellæ, often none. The majority of lamellæ were orientated after (112), fewer after $(1\bar{1}2)$, while (150) and $(1\bar{5}0)$ both contained a considerable number.

Projections of the elongated edges of lamellæ after (112) on (001) formed often about +73°, sometimes −14°, with the *a*-axis. Other measurements did not seem to represent general orientations.

Table 3

$Ab_{91}An_9$; $n = 1·535$						
Form	Measured		ρ		ϕ	
	i	r	Calculated from measurements	Calculated from axial ratios	Measured	Calculated from axial ratios
Pole: Normal to 001 (ρ_P and ϕ_P)						
112	47° 18′	20° 26′	20° 53′	20° 40′	58° 41′	58° 57′
	58 45	12 42	21 2		58 37	
	59 39	11 36	20 52		58 55	
$1\bar{1}2$	55 5	17 57	21 56	21 48	56 24	56 6
	58 39	15 12	21 49		55 49	
	59 55	14 20	21 58		56 24	
Pole: Normal to 010 (ρ_M and ϕ_M)						
150	54 21	10 54	19 31	19 24	63 31	63 27
$1\bar{5}0$	47 40	15 12	19 19	19 17	63 20	
	54 45	9 49	19 16		63 58	

Oligoclase from near Statesville, Iredell County, North Carolina.[*]

The feldspar.—The cleavage pieces had a grayish-brown color, and were not quite fresh, being clear in spots only.

Extinction angle on (001) = + 1/2°
" " " (010) = + 8°
$\beta = 1·54$
Composition : $Ab_{82}An_{18}$, oligoclase.[†]

The cleavage pieces form polysynthetic twins after the albite law, the lamellæ of the one individual being comparatively broad, those of the other extremely narrow.

The hematite lamellæ.—In the clear spots of the feldspar there were numerous lamellæ which produced a strong aventurization. The lamellæ formed sometimes long narrow strips and sometimes distorted six-sided or rhomb-shaped plates. The largest dimensions of the strips were $0·8 \times 0·03^{mm}$; the plates were seldom more than $0·3 \times 0·1^{mm}$.

Orientation of the lamellæ.—The goniometric measurements are given in Table 4. The planes of orientation were: (001), (010), (112), $(1\bar{1}2)$, $(\bar{1}13)$, $(0\bar{2}1)$, (150), $(1\bar{5}0)$.

The most prominent set of lamellæ were parallel to (112), (150) and $(1\bar{5}0)$. After $(1\bar{1}2)$ there were fewer, and after the other planes, $(\bar{1}13)$, $(0\bar{2}1)$, (001) and (010), very few.

The projections of the long edges of lamellæ after (112) on (001) often formed about +74° with the *a*-axis. These lamellæ were elongated, strip-shaped, and traversed a great number of twinning lamellæ. Six-sided lamellæ after (112) were oriented with the projections of one of the edges on (001) forming −80° with the *a*-axis. The lamellæ after $(1\bar{1}2)$ were often elongated with the projections of the long edges on (001) approximately parallel to the *a*-axis. Lamellæ after (150) and $(1\bar{5}0)$ had distorted hexagonal or rhombic outlines. The projections of their elongated edges on (010) sometimes formed +11° with the *a*-axis.

Oligoclase from Kragerö, Norway.[‡]

The feldspar.—The cleavage pieces have a strong, red color, and are usually perfectly fresh and transparent.

Extinction angle on (001) = +1°
" " " (010) = +7°
$\beta = 1·543$
Composition : $Ab_{80}An_{20}$, oligoclase.

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[*] Specimens from U. S. National Museum, No. 80324.

[†] G. F. Kunz has described orthoclase sunstone from Statesville, N. C. (History of the Gems found in North Carolina, p. 27). This may be the same sunstone as the one described here. Owing to the very fine twinning striation the feldspar might have been mistaken for orthoclase, by a macroscopic examination.

[‡] Specimens from U. S. National Museum, No. 44776.

TABLE 4

$Ab_{82}An_{18}$; $n = 1·540$

Form	Measured		ρ		ϕ	
	i	r	Calculated from measurements	Calculated from axial ratios	Measured	Calculated from axial ratios
Pole: Normal to 001 (ρ_P and ϕ_P)						
112	46° 40′	20° 53′	20° 47′	20° 43′	58° 7′	58° 41′
	72 40	6 5	21 7		59 11	
$1\bar{1}2$	46 55	23 20	21 36	21 44	56 9	56 23
	72 32	7 48	21 42		57 8	
$\bar{1}13$	46 56	17 12	19 42	19 35	56 9	56 23
$0\bar{2}1$	[1] 62 24	31 29	46 53	46 48	0 0	0 0
	[2] 69 20	25 4	46 47		0 0	
	[3] 69 42	25 27	46 37		0 0	
Pole: Normal to 010 (ρ_M and ϕ_M)						
150	48 58	14 50	19 22	19 28	64 2	63 31
	57 7	8 50	19 24		63 51	
	58 4	8 58	19 38		63 21	
$1\bar{5}0$	48 29	13 55	19 2	19 18	63 53	
	56 48	8 32	19 14		63 38	

[1] $\lambda = 93° 37'$ [2] $\lambda = 93° 55'$ [3] $\lambda = 93° 57'$

The feldspar consisted of large, single individuals, or was sometimes composed of broad twinning lamellæ after the albite law.

The hematite lamellæ.—As the lamellæ were large and present in great numbers the aventurization was exceedingly strong, especially on (001).

Large lamellæ, measuring 2 × 1^{mm} or more, were numerous, but all sizes down to the very smallest were seen.

The outlines were sometimes six-sided and often rhomb-shaped or elongated. Eight-sided or quite irregular outlines were also frequently seen. (Plate II, fig. 1.)

Opaque hexagonal lamellæ were sometimes arranged in regular groups with the edges of each lamella parallel to the six-sided outlines of the groups.

Orientation of the lamellæ.—The goniometric measurements are given in Table 5. The planes of orientation were: (001), (010), (112), ($1\bar{1}2$), (150), ($1\bar{5}0$), (110).

TABLE 5

$Ab_{80}An_{20}$; $n = 1{\cdot}543$

Form	Measured		ρ		ϕ	
	i	r	Calculated from measurements	Calculated from axial ratios	Measured	Calculated from axial ratios
Pole: Normal to 001 (ρ_P and ϕ_P)						
112	59° 35′	12° 14′	20° 57′	20° 43′	57° 54′	58° 41′
	61 17	10 52	20 50		58 0	
			[1] 20 53		58 8	
$1\bar{1}2$	60 39	14 23	21 50	21 44	56 36	56 23
	61 20	13 8	21 34		57 2	
Pole: Normal to 010 (ρ_M and ϕ_M)						
150			[1] 19 30	19 28	63 33	63 31
$1\bar{5}0$			[1] 19 12	19 18	63 55	

[1] Direct measurement.

Lamellæ after (110) were identified in sections after (001) and (010) by the measurements: $\phi_P = 58°$; $\phi_M = 64°$.

There were numerous lamellæ after (112) and comparatively few after ($1\bar{1}2$). After (150) and ($1\bar{5}0$) there were also many; after (001), (010), and (110) very few.

For some of the lamellæ after (112) the projections of the longest edges on (001) were parallel to the *a*-axis. For other lamellæ in the same plane the edges formed +60° or +47° with the *a*-axis.

*Oligoclase from Tvedestrand, Norway.**

The occurrence at Tvedestrand has been described by Weiby† as consisting of veins in gneiss, the essential minerals of the veins being oligoclase (sunstone) and quartz; accessory minerals, apatite, hematite, cordierite, hornblende and zircon.

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* Specimens from the Mineralogical Museum of Kristiania University.

† Cited by Th. Scheerer, loc. cit., p. 154.

The feldspar.—The cleavage pieces were generally fresh and clear, of a strong, red color.

Extinction angle on (001) = +1°
" " " (010) = +3·5°
$\beta = 1{\cdot}545$
Composition: $Ab_{76}An_{24}$, oligoclase in agreement with Scheerer's analysis.*

The oligoclase was generally twinned both after the albite law and the pericline law, most of the twinning lamellæ being broad (often more than 1^{mm}). The pericline striation on (010) formed +10° with the a-axis. Sometimes broad cleavage pieces, without any twinning, were seen.

The hematite lamellæ.—In some specimens the hematite lamellæ were very scarce; in others they were densely crowded and of large size, producing the most brilliant aventurization. Lamellæ measuring 3×2^{mm} or even more were frequently seen. The outlines were hexagonal, rhomb-shaped or irregular.

The lamellæ after (010) were often larger and more irregularly outlined than the others.

Some few lamellæ were opaque, but most of them were transparent with the usual absorption colors.

Orientation of the lamellæ.—The determinations of the planes of orientation made by Scheerer (see p. 353) and Tertsch (see p. 354) have already been mentioned. Of these only Scheerer's have been partly confirmed by the present study (viz., the faces (001), (010) and (110)). The planes given by Tertsch, (538) and (417), could be found neither on the Tvedestrand sunstone nor on any of the other varieties examined. That Scheerer's determination of $(22\bar{1})$ as a plane of orientation is wrong was intimated by E. Reusch† and further proved by Tertsch.‡

According to my measurements (of which Table 6 contains those made with goniometer) the following forms were planes of orientation: (001), (010), (112), $(1\bar{1}2)$, (150), $(1\bar{5}0)$, (110). Of these (112) contained the largest number of lamellæ which cause the brilliant aventurization on (001); $(1\bar{1}2)$ contained but few. After (150) and $(1\bar{5}0)$ there were numerous lamellæ producing a strong aventurization on (010). Along the other faces (001), (010) and (110) there were comparatively few, none causing aventurization on the cleavage faces.

The face (110) was identified as plane of orientation by microscopic measurements: $\phi_P = 56° - 57°$; ϕ_M about 62°.

The projections on (001) of the elongated edges of lamellæ after (112) were often parallel to the a-axis; some formed +72°

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*Loc. cit., p. 155.

† Pogg. Ann., cxvi, 396, 1862.

‡ Loc. cit., p. 248.

TABLE 6

$Ab_{78}An_{22}$; $n = 1{\cdot}545$

Form	Measured		ρ		ϕ	
	i	r	Calculated from measurements	Calculated from axial ratios	Measured	Calculated from axial ratios
Pole : Normal to 001 (ρ_P and ϕ_P)						
112	45° 4′	22° 11′	20° 43′	20° 44′	57° 55′	58° 34′
	50 32	18 2	20 46		58 17	
	54 32	15 2	20 45		58 26	
	62 40	10 1	20 47		58 22	
	67 26	7 24	20 44		57 49	
	68 40	7 3	20 49		58 24	
			[1] 20 50		58 27	
$1\bar{1}2$	48 30	22 31	21 42	21 42	56 48	56 18
	52 16	19 21	21 35		56 7	
	62 40	12 12	21 29		56 34	
	66 14	10 55	21 41		56 29	
Pole : Normal to 010 (ρ_M and ϕ_M)						
150			[1] 19 27	19 30	63 22	63 33
			[1] 19 40		63 16	
$1\bar{5}0$	45 53	17 6	19 20	19 19	63 55	
	46 12	16 39	19 16		63 26	
			[1] 19 17		63 29	

[1] Direct measurement.

with the *a*-axis. Projections of the long edges of lamellæ after (150) and ($1\bar{5}0$) formed −77° or −84° with the *a*-axis. Lamellæ after (110) were generally elongated approximately parallel to (001).

Oligoclase from Aamland, Söndeled, Norway.[*]

The occurrence is much like the one at Tvedestrand (according to Weiby's description of the latter). At the place where the specimens were found the prevailing gneiss included a great number of irregular pegmatite veins varying in thickness from 0·5 m. down to a few mm. The main minerals of the veins were oligoclase (sunstone), quartz and cordierite; accessory minerals, hornblende, biotite, apatite and magnetite.

The feldspar.—The oligoclase is generally very fresh, in places strong red from the hematite inclusion, sometimes grayish or colorless.

Extinction angle on (001) = +1° — 2°
" " " (010) = +5°
$\beta = 1{\cdot}545$
Refractive index of glass, $n_{Na} = 1{\cdot}507 \pm 0{\cdot}001$
Composition : $Ab_{78}An_{22}$, oligoclase, practically the same as the sunstone from Tvedestrand.

The crystals are often twinned with coarse lamellæ, after the albite and pericline laws, thus showing striation on (001) and (010). Very often, also, large pieces without twinning are observed.

The aventurization was of a variable intensity and seldom uniform over large pieces; many specimens contained no reflecting lamellæ; others contained many and showed a beautiful aventurization, not inferior to that of the best Tvedestrand specimens.

The hematite lamellæ.—The lamellæ were large as in the Tvedestrand sunstone, up to 2 × 3^{mm} or sometimes more. Most of them were not six-sided, but showed distinct, unsymmetrical eight or ten-sided outlines. Often they were quite irregular. Fig. 2, Pl. II, and fig. 1, Pl. III, show the characteristic shape of lamellæ in sections after (001).

Orientation of the lamellæ.—The angles of the goniometric measurements are given in Table 7. The planes of orientation were: (001), (010), (112), $(1\bar{1}2)$, (150), $(1\bar{5}0)$, (110), $(1\bar{1}0)$. Of these (112) contained the larger number of lamellæ; $(1\bar{1}2)$ only a few; (150) and $(1\bar{5}0)$ contained a considerable number, the other forms very few.

The determinations of the planes (110) and $(1\bar{1}0)$ were based chiefly on the microscopic measurements; for (110): $\phi_P =$ 57° 10′; $\phi_M =$ 63° 30′; for $(1\bar{1}0)$; $\phi_P =$ 57° 35′; $\phi_M =$ 63° 58′.

In one case direct goniometric measurements could be made on exposed lamellæ after (110): $\rho_M =$ 61° 5′; $\phi_M =$ 63° 55′.

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[*] This locality was recently discovered by Mr. Törje Törjesen, Risör. The specimens for the present description were collected by the author at the locality.

TABLE 7

$Ab_{76}An_{24}$; $n = 1·545$

Form	Measured		ρ		ϕ	
	i	r	Calculated from measurements	Calculated from axial ratios	Measured	Calculated from axial ratios
			Pole : Normal to 001 (ρ_P and ϕ_P)			
112	46° 27′	21° 17′	20° 47′	20° 44′	58° 3′	58° 34′
	49 58	18 28	20 48		57 56	
	57 26	13 13	20 47		58 19	
$1\bar{1}2$	46 27	23 9	21 22	21 42	56 57	56 18
	49 58	21 7	21 36		57 6	
	57 26	15 46	21 36		56 44	
			Pole : Normal to 010 (ρ_M and ϕ_M)			
150	46 32	17 10	19 31	19 30	63 43	63 33
			[1] 19 34		63 34	
			[1] 19 28		63 50	
$1\bar{5}0$	46 34	16 40	19 22	19 19	63 17	
	47 35	16 0	19 25		63 42	
			[1] 19 20		63 29	

[1] Direct measurement.

Projections on (001) of the longer edges of lamellæ after (112) formed often + 72° with the a-axis. Lamellæ after (150) and ($1\bar{5}0$) were oriented with the projections of the long edges on (010), forming about −79° with the a-axis.

*Labradorite from Labrador.**

The feldspar.—The cleavage pieces were fresh, of gray color and showed a beautiful labradorization on cleavage faces of (010).

Extinction angle on (001) = 5·5°
" " " (010) = 16°
$\beta = 1·558$

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* Specimens from the collection of the Geophysical Laboratory.

Composition: $Ab_{49}An_{51}$, a labradorite very near andesine.

The cleavage pieces were twinned with coarse lamellæ after the albite law.

The hematite lamellæ.—There were but few reflecting lamellæ and the aventurization was accordingly very indistinct. Most of the lamellæ were opaque, but some were transparent with the characteristic colors of hematite. They were often linear, but sometimes approximately six-sided or irregularly rounded. The largest measured 0·03^{mm} in diameter.

Orientation of the lamellæ.—The goniometric measurements are given in Table 8. The planes of orientation were: (112), ($1\bar{1}2$), (150), ($1\bar{5}0$) each with about the same number of lamellæ. The linear, strip-shaped lamellæ after (112) and ($1\bar{1}2$) were generally oriented with the projections of the long edges on (001) parallel to the *a*-axis. The long edges of lamellæ after (150) and ($1\bar{5}0$) were frequently parallel to the *c*-axis.

TABLE 8

$Ab_{49}An_{51}$; $n = 1·558$

Form	Measured		ρ		ϕ	
	i	*r*	Calculated from measurements	Calculated from axial ratios	Measured	Calculated from axial ratios
Pole: Normal to 001 (ρ_P and ϕ_P)						
112	57° 20′	14° 12′	20° 53′	20° 51′	57° 53′	57° 58′
$1\bar{1}2$	57 14	16 24	21 33	21 34	57 23	57 10
Pole: Normal to 010 (ρ_M and ϕ_M)						
150	55 30	11 32	19 39	19 39	63 54	63 43
	57 39	10 37	19 48		64 4	
$1\bar{5}0$	54 49	9 7	18 44	19 23	63 46	
	55 48	8 23	18 48		63 55	

It should be noticed that the plane of labradorization on (010) does not coincide with any of the planes of orientation of the aventurizing lamellæ.

Microcline Perthite from Perth, Ontario, Canada.[*]

The feldspar.—The aventurine feldspar from Perth was described by Des Cloizeaux[†] as an orthoclase perthite. The

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[*] Specimens from U. S. National Museum; Lea collection, No. missing.

[†] Ann. Chim. Phys. (5), ix, 465, 1875.

specimens examined by me consisted of microcline perthite made up of copper red microcline, and colorless albite. The microcline showed an exceedingly fine cross hatching invisible with low magnification and in places hardly detectable even with a high magnifying power of the microscope. The albite forms coarse inclusions extended approximately parallel to the *c*-axis but of very irregular cross sections.

The hematite lamellæ. — The reflecting lamellæ were restricted to the microcline, the albite never containing any. They were very small, seldom more than 0·05^{mm} in diameter, of rather regular outlines, hexagonal or rhomb-shaped, or sometimes forming linear strips.

Orientation of the lamellæ.—The goniometric measurements are stated in Table 9. The following faces were planes of orientation: (001), (010), (112), $(1\bar{1}2)$, (150), $(1\bar{5}0)$.* After (112, $(1\bar{1}2)$, (150) and $(1\bar{5}0)$ there were numerous lamellæ causing a distinct aventurization on the cleavage faces; after (001) and (010) there were very few.

TABLE 9

Microcline: $n = 1{\cdot}523$

Form	Measured		ρ		ϕ	
	i	r	Calculated from measurements	Calculated from axial ratios	Measured	Calculated from axial ratios
Pole: Normal to 001 (ρ_P and ϕ_P)						
112	49° 2′	18° 50′	20° 59′	20° 57′	56° 15′	56° 38′
	54 22	15 10	21 4		56 32	
Pole: Normal to 010 (ρ_M and ϕ_M)						
150	40 39	17 9	18 15	18 41	64 27	63 57
	56 11	6 48	18 46		64 10	

Many of the lamellæ after (112) and $(1\bar{1}2)$ were oriented with the projection of their elongated edges on (001) approximately parallel to the *a*-axis. The elongation of the lamellæ after (150) and $(1\bar{5}0)$ was often approximately parallel to the *c*-axis.

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* For the sake of comparison with the plagioclase, the positive and negative faces of forms like (112), that is 112 and $1\bar{1}2$, are put down as distinct forms, although their angles are referred to the monoclinic axes of orthoclase (see p. 364 and Table 1) and therefore are the same.

Microcline Perthite from Mineral Hills, Middletown, Delaware County, Pennsylvania.[*]

The feldspar.—The aventurine feldspar from Mineral Hills was described by Des Cloizeaux first as orthoclase[†] and later as microcline perthite.[‡]

The albite inclusions are regularly extended in the direction of the *c*-axis, but have very irregular cross sections, often as much as 1^{mm} broad. On (001) we therefore see very irregular patches or bands of albite in the microcline, on (010) we see regular alternate stripes of microcline and albite approximately parallel to the *c*-axis. The microcline is greenish-gray with red spots; under the microscope it shows the ordinary coarse cross hatching. The albite is colorless and shows the usual polysynthetic twinning after the albite law.

The hematite lamellæ.—Aventurization was only observed in the red spots of the microcline; the other parts of the microcline and the albite contained no hematite lamellæ.

The lamellæ are distorted six-sided, rhomb-shaped or form elongated strips or irregular patches. The elongated strips measure at most $0{\cdot}2 \times 0{\cdot}1^{\mathrm{mm}}$, the more irregular lamellæ about $0{\cdot}1 \times 0{\cdot}1^{\mathrm{mm}}$.

Orientation of the lamellæ.—The goniometric measurements are contained in Table 10. The lamellæ were oriented after the faces: (001), (010), (112), $(1\bar{1}2)$, (150), $(1\bar{5}0)$. Projections on (001) of elongated edges of lamellæ after (112) and $(1\bar{1}2)$ form often 20° with the *a*-axis. For other lamellæ the corresponding angle is 76°. The angle between the projections of the elongated edges of lamellæ after (150) and $(1\bar{5}0)$ on (010) and the *a*-axis is often about −80°.

Microcline Perthite from Näskilen, Arendal, Norway.[§]

The feldspar.—The cleavage pieces were rather fresh, of a brownish-gray color. The cleavage faces were often curved.

The feldspar was a microperthite with very fine, rod-shaped albite inclusions of elliptical cross sections and with the elongated direction approximately parallel to the *c*-axis. The microcline showed a very fine cross hatching.

The hematite lamellæ.—The aventurization was distinct, produced by numerous small lamellæ which never measured more than $0{\cdot}2^{\mathrm{mm}}$ in diameter. The lamellæ often formed linear strips, but were also sometimes approximately hexagonal or rhomb-shaped.

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[*] Specimens from U. S. National Museum; No. 78700.

[†] (Orthose aventuriné) Nouv. Rech., 1867, pp. 153 and 206.

[‡] Ann. Chim. Phys. (5), ix, pp. 534, 460, 463, 1876.

[§] Specimens from the Mineralogical Museum of Kristiania University.

TABLE 10

Microcline; $n = 1{\cdot}523$

Form	Measured		ρ		ϕ	
	i	r	Calculated from measurements	Calculated from axial ratios	Measured	Calculated from axial ratios
Pole: Normal to 001 (ρ_P and ϕ_P)						
112	51° 27′	16° 55′	20° 58′	20° 57′	56° 16′	56° 38′
	51 50	16 18	20 51		56 24	
	64 50	8 19	20 57		56 23	
	65 4	8 4	20 54		56 46	
Pole: Normal to 010 (ρ_M and ϕ_M)						
150	55 3	6 39	18 28	18 41	63 47	63 57
	55 31	6 48	18 37		63 57	
	59 13	4 46	18 44		63 20	

Orientation of the lamellæ.—Table 11 contains the goniometric measurements. The following faces were planes of orientation: (001), (010), (112), (1$\bar{1}$2), (150), (1$\bar{5}$0). Of these only (112), (1$\bar{1}$2), (150) and (1$\bar{5}$0) contained a large number of lamellæ. After (001) and (010) there were very few.

TABLE 11

Microcline; $n = 1{\cdot}523$

Form	Measured		ρ		ϕ	
	i	r	Calculated from measurements	Calculated from axial ratios	Measured	Calculated from axial ratios
Pole: Normal to 001 (ρ_P and ϕ_P)						
112	57° 7′	13° 27′	21° 2′	20° 57′	57° 21′	56° 38′
Pole: Normal to 010 (ρ_M and ϕ_M)						
150	52 27	10 0	18 57	18 41	64 38	63 57

Projections on (001) of the long edges of lamellæ after (112) and $(1\bar{1}2)$ formed frequently 15° with the *a*-axis; others were approximately parallel to the *a*-axis. Projections on (010) of the elongated edges of lamellæ after (150) and $(1\bar{5}0)$ formed often $-83°$ with the *a*-axis.

*Microcline Perthite from Stene, Sannökedal, Norway.**

The occurrence is an ordinary granite pegmatite dike (feldspar quarry) containing microcline perthite, plagioclase (oligoclase), quartz and biotite as main minerals and a number of other minerals in smaller quantities. Different varieties of graphic granite are abundant.

The feldspar.—The perthite structure was in part coarse with visible lamellæ of albite (after 110), in part a very fine microperthite structure, with extremely thin rod-shaped inclusions of albite oriented approximately parallel to the *c*-axis. There were all transitions between these two structures, both often being found in the same little cleavage piece. The coarse perthite often formed isolated patches in the microperthite.

In the coarse perthite the microcline was developed with the ordinary cross hatching. In the microperthite the microcline structure was very fine and there was no regular cross hatching.

The hematite lamellæ.—The aventurization was restricted to the microperthitic parts of the feldspar and appeared with medium intensity about equally distinct on either of the two cleavage faces.

The lamellæ measured at most $0{\cdot}1^{mm}$ in diameter and were very variable as to shape. Some showed very regular hexagonal outlines, others were rhomb-shaped or elongated and still others perfectly irregular.

The lamellæ parallel to (001) were often collected in groups with regular hexagonal or rhomb-shaped outlines. The single lamellæ were small, mostly irregular, but sometimes hexagonal or rhomb-shaped and with the edges parallel to the outlines of the groups. The groups often measured $1 - 2^{mm}$ in diameter and their outlines were definitely oriented.

Orientation of the lamellæ.—The goniometric measurements are given in Table 12. The planes of orientation were the following faces: (001), (010), (112), $(1\bar{1}2)$, (150), $(1\bar{5}0)$, (110), $(1\bar{1}0)$. Most of the lamellæ were parallel to (112), $(1\bar{1}2)$, (150) and $(1\bar{5}0)$ with about equally many after each; a considerable number were also oriented after (001), (010), (110) and $(1\bar{1}0)$.

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*This locality was discovered some years ago by Mr. Peder P. Tangen, Kragerö. The specimens examined were partly obtained from the Mineralogical Museum of Kristiania University, partly collected by the author at the locality.

TABLE 12

Microcline; $n = 1{\cdot}523$

Form	Measured		ρ		ϕ	
	i	r	Calculated from measurements	Calculated from axial ratios	Measured	Calculated from axial ratios
Pole: Normal to 001 (ρ_P and ϕ_P)						
112	47° 40′	19° 20′	20° 47′	20° 57′	56° 19′	56° 38′
	50 17	18 14	21 5		56 42	
	51 24	16 34	20 50		56 55	
Pole: Normal to 010 (ρ_M and ϕ_M)						
150	46 21	14 5	18 47	18 41	64 20	63 57
	52 5	7 59	18 13		63 50	

The form (110) (embracing 110 and 1$\bar{1}$0) was established by the microscopic measurements: $\phi_P = 56{\cdot}2°$; $\phi_M = 64{\cdot}3°$.

The edges of the lamellæ after (001) were sometimes parallel to the *a*-axis and also occasionally parallel to the *b*-axis. More frequently, however, they formed oblique angles with the *a*-axis. Angles of 40° and 70° between the *a*-axis and the elongated edges of lamellæ (or the outlines of the groups of lamellæ described) were measured. Lamellæ after (010) were often oriented with one of the edges perpendicular to the *a*-axis more seldom forming +50° with the *a*-axis. The lamellæ after (112), (1$\bar{1}$2), (150) and (1$\bar{5}$0) were generally so small and irregular that no definite measurements of the orientation of their edges could be made.

Miscellaneous Occurrences.

Besides the varieties described in the preceding pages, a number of other specimens were examined more superficially.* All these specimens showed a very weak aventurization and the measurements were only approximate. The results for all were that the aventurization on (001) was due to lamellæ

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* In the literature we find mentioned a considerable number of occurrences besides those described or referred to in this paper. No actual descriptions of these aventurine feldspars have been given, however, and it is therefore of minor interest to list the references, most of which can be easily found in standard handbooks of mineralogy or treatises on gems. See for instance: Max Bauer, Edelsteinskunde; G. F. Kunz, Gems and Precious Stones of North America.

oriented after (112) or (1$\bar{1}$2) and that on (010) was due to lamellæ after (150) and (1$\bar{5}$0), that is, the same as in the other specimens examined. The measurements were made with the microscope. The localities are given below, together with brief characteristics of the different specimens.

Mörefjer, Arendal, Norway.†—Microcline, microperthite of normal structure. Hematite lamellæ few, transparent.

Rosaas, Iveland, Norway.†—Microcline perthite partly with visible albite lamellæ, partly a microperthite. Strongest aventurization on (010). Hematite lamellæ sometimes very regular, six-sided or rhomb-shaped, transparent. Numerous lamellæ of mica after faces of (110).

*Hiltveit, Iveland, Norway.**—Microcline microperthite with very fine microcline structure and thin rod-shaped albite intergrowths. Strongest aventurization on (010). Hematite lamellæ sometimes elongated and sometimes rather regular, six-sided; transparent.

Renfrew, Canada.†—A microcline perthite of very coarse structure. Few opaque hematite lamellæ.

SUMMARY.

A number of varieties of aventurine feldspars were examined. Orientation angles of the reflecting lamellæ were measured, chiefly with the goniometer, and the properties of the lamellæ were determined under the microscope. Brief discussions of the optical problems are included in the record of these examinations.

The reflecting lamellæ are always oriented after simple crystal forms of which (112), (1$\bar{1}$2), (150) and (1$\bar{5}$0) occur as planes of orientation in all varieties, the first two causing aventurization on (001), the last two on (010). The forms (001), (010), (110) and (1$\bar{1}$0) also frequently contain reflecting lamellæ. Exceptionally (0$\bar{2}$1) and ($\bar{1}$13) are planes of orientation. The orientation of the edges of the lamellæ is evidently regular but simple crystallographic relations could not, in general, be found.

The reflecting lamellæ were determined as hematite. They vary widely from one variety to another as to shape and size, showing hexagonal, eight- or ten-sided, rhomb-shaped, strip-shaped or irregular outlines. The largest measured $3{\cdot}5^{mm}$ in one direction, the smallest were of submicroscopic size. The absorption colors are those characteristic of hematite. It was shown that the colors in reflected light are interference colors of thin films. By means of these colors the thickness of the transparent lamellæ could be approximately determined. It

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* Specimens from the Mineralogical Museum of Kristiania University.

† Specimens from U. S. National Museum; No. 83218.

was found to vary between 50$\mu\mu$ and 500$\mu\mu$. The lamellæ were shown to possess no appreciable pleochroism. The apparent pleochroism observed in lamellæ forming large angles with the section was explained as due to the effect of polarization by reflection and refraction at the surface of the lamellæ. The appearance of interference spectra in these lamellæ was explained as due to the action of the lamellæ as polarizers or analyzers for the wedge-shaped parts of the feldspar that lie above or below them in the sections.

Thermal experiments with one of the varieties showed that the hematite lamellæ persist up to about 1235°. At this temperature they disappeared, presumably by melting together with a small part of the surrounding feldspar to thin, invisible glass films. The feldspar remained otherwise unchanged (crystallized). By heating at lower temperatures some of the lamellæ (originally opaque ones) reappeared in the same places and with the same outlines as before. By a long heating at temperatures around 1050° (of cleavage pieces not previously heated) the opaque lamellæ generally became transparent and the others became a little lighter.

The origin of the hematite lamellæ was explained as due to unmixing of an originally homogeneous feldspar which contained iron oxides in solid solution. Thin lamellæ of hematite then separated along certain structural planes of the feldspar.

In the concluding section all the specimens examined are described and the measurements tabulated.

The Geophysical Laboratory of the
Carnegie Institution of Washington,
Washington, D. C., July 16, 1915.

Fig. 1.

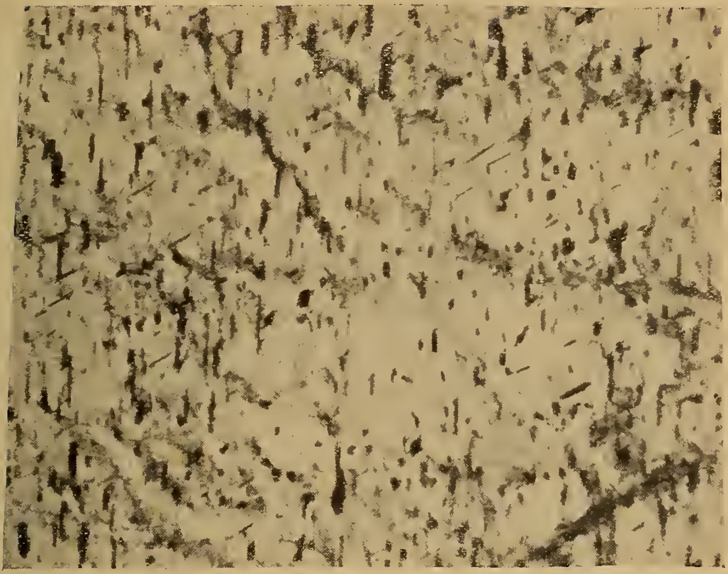


Fig. 2.

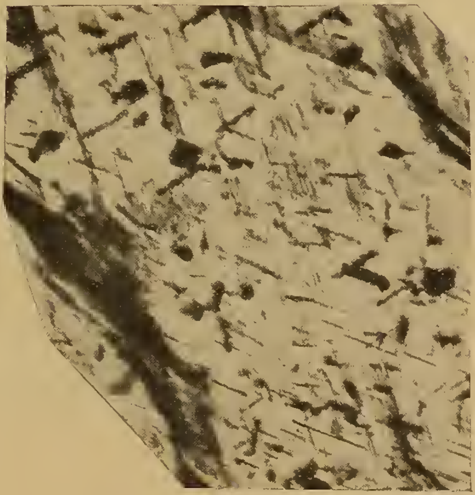


Fig. 1.

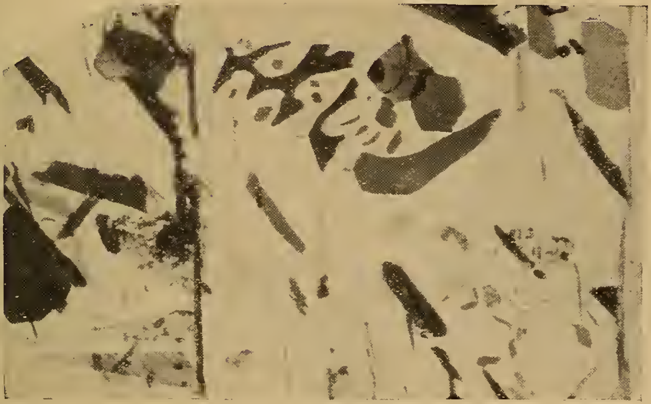
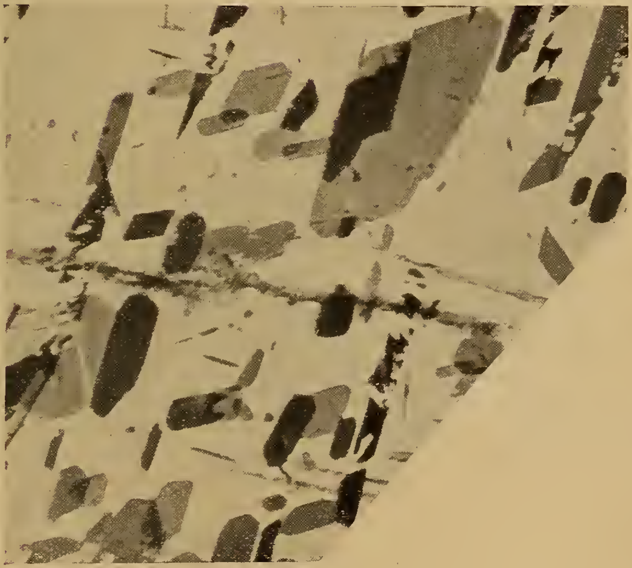


Fig. 2.



EXPLANATION OF PLATES.

Plate I.

Fig. 1. Albite (aventurine feldspar) from Fisher Hill Mine. Thick section after (001). Ordinary light. Magnified about 30 diameters.

The vertically elongated patches are hematite lamellæ arranged parallel to (112), the long edges being projections on (001) parallel to *a*-axis. The streaks running in the direction from lower left to upper right quadrant are also hematite lamellæ parallel to (112).

Fig. 2. Albite (aventurine feldspar) from Fisher Hill Mine. Thick section after (010). Ordinary light. Magnified about 30 diameters.

The large patches are hematite lamellæ parallel to (010); horizontal streaks lamellæ parallel to (0$\bar{2}$1). Streaks running from upper left to lower right quadrant at small angle with horizontal are lamellæ parallel to (112) and (1$\bar{1}$2). Streaks from upper left to lower right at large angle with the horizontal are lamellæ parallel to (150) and (1$\bar{5}$0) with the elongated edges parallel to the *c*-axis.

Plate II.

Fig. 1. Oligoclase (aventurine feldspar) from Kragerö. Thick section after (001). Ordinary light. Magnified about 30 diameters.

Elongated patches running from upper left to lower right quadrant are hematite lamellæ parallel to (150). Other patches are chiefly lamellæ parallel to (112).

Fig. 2. Oligoclase (aventurine feldspar) from Aamland. Thick section after (001). Ordinary light. Magnified about 30 diameters.

Chiefly hematite lamellæ parallel to (112); some parallel to (1$\bar{1}$2). The variations in the outlines of the lamellæ are distinctly seen.

Plate III.

Fig. 1. Oligoclase (aventurine feldspar) from Aamland. Thick section after (001). Ordinary light. Magnified about 50 diameters.

Hematite lamellæ parallel to (112) showing various outlines. Near the center two lamellæ parallel to ($\bar{1}$50) running steeply from lower left to upper right.

ART. XXIX.—*Anodic Potentials of Silver: II. Their Rôle in the Electrolytic Estimation of the Halogens*; by JOHN HENRY REEDY.

(Contributions from the Kent Chemical Laboratory of Yale Univ.—cclxxi.)

THE first attempt at the estimation of the halogens by electrolytic fixation on silver electrodes was made by Vortmann.* The halides in alkaline solution were electrolyzed between a copper cathode and a silver anode, using a potential of about two volts. At the end of the electrolysis the anode was ignited to decompose the silver oxide formed during the process, and the deposited halogen was determined by gain in weight. Even in alkaline solution small amounts of silver were transported to the cathode. The deposit was not very adherent, and Vortmann sought to overcome this by adding sodium-potassium tartrate to the solution. The problem of separating the halogens was not considered.

The quantitative separation and estimation of the halogens was first attempted by Specketer.† The halides were dissolved in 0·5 molar sulphuric acid, and during the electrolysis a stream of hydrogen was constantly passed through the solution to provide stirring, and at the same time to make the platinum cathode function as a hydrogen electrode. Considering the anode reversible with respect to the Ag·-ion, Specketer assumed that the maximum anode potential required in any determination would be the potential of a silver electrode in a saturated solution of the silver halide in question, and that this value could be calculated from solubility data, by means of the Nernst formula for electromotive force. In this way he calculated the potentials necessary for the precipitation of the halogens to be —·06 volts‡ for iodine, +·15 volts for bromine and +·50 volts for chlorine; that is, a potential of —·06 volts should deposit all the iodine free from chlorine and bromine, and +·15 volts all the bromine free from chlorine. In practice somewhat larger potentials were found necessary. In order to make this separation satisfactorily, Specketer found that the following precautions must be observed: (1) A constant voltage must be employed; (2) a definite acidity of solution must be maintained,—for example, 0·5 molar sulphuric acid: (3) atmospheric oxygen must be excluded, since it has a marked effect on the potential of the hydrogen electrode. Specketer found it impossible to determine chlorine on a silver anode,

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* Monatsh. Chem., xv, 280; xvi, 674.

† Zeitschr. Elektroch., iv, 542.

‡ Referred to the hydrogen electrode in 0·5 molar sulphuric acids as 0 volts.

since some silver always went into solution. He therefore recommended estimating chlorine volumetrically after the iodine and bromine had been precipitated. No attention seems to have been given by Specketer to the possibility that, for certain concentrations, halogens might be deposited simultaneously.

E. F. Smith and his collaborators* have studied extensively the electrolytic precipitation of the halogens on silver anodes. In the same laboratory the so-called "double-cup" was developed by Hildebrand, by means of which both metal and halogen are determined in one electrolysis. Very accurate results were reported.

Gooch and Read,† and Peters,‡ however, found the estimation of chlorine by deposition on silver anodes to give results that were "irregular and always low," owing to a tendency of the silver to be dissolved from the anode, and to be transported to the cathode, or precipitated as silver chloride in the solution.

Very recently Boettger and Kelly § have proposed a modification of the Hildebrand "double-cup" method. It consists in adding an excess of a salt whose cation is more readily deposited than the ions of the alkali metals, such as cadmium sulphate. The mercury dissolves the deposited metal, and owing to the high over-voltage of the hydrogen on the amalgam cathode, no hydrogen is evolved, and the solution remains neutral. No report was made of estimating chlorine in this way. Presumably the authors found that it was not practicable. The determination of the decomposition potentials of solutions of potassium iodide, potassium bromide and potassium chloride of arbitrary concentration led Boettger and Kelly to the conclusion that the iodine could be separated from bromine and chlorine, but not bromine from chlorine. Satisfactory results were obtained. The methods used were more or less empirical, and no attention was given to the effect of varying the concentration of the halide solutions.

Experimental Part.

Preliminary Experiments.—Solutions of potassium chloride were dissolved in various dilute acids (0·5 molar sulphuric, 0·33 molar phosphoric, 0·5 molar oxalic, and 1·0 molar formic) and electrolyzed between a platinum cathode and a rotating silver anode, using very low tensions,—50 to 200 millivolts. In all cases it was found that shortly before the precipitation was

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* Withrow, Jour. Amer. Chem. Soc., xxviii, 1356; Hildebrand, ibid., xxix, 447; McCutcheon, ibid., xxix, 1445, 1460; Lukens, ibid., xxix, 1455; Goldbaum and Smith, ibid., xxx, 1705; xxxii, 1468.

† This Journal, xxviii, 435.

‡ Ibid., xxxii, 365.

§ Verh. Ges. deutsch. Aertze, 1913 (1914), II, 361.

complete the silver began to dissolve. The weight of the chlorine found was less than the theory by amounts varying from 1 to 6 milligrams.

To ascertain if the solution of the silver could be due to oxidation at the anode, reducing agents like urea, formic acid and acetaldehyde were added to the electrolyte. Such expedients did not prevent the loss of silver from the anode, as minute flecks of the metal or its salts always appeared in the solution sooner or later.

Determinations in neutral solutions were also tried, and the results obtained in this case were likewise always too low.

Isolation of the Anode Potential.—In all the above experiments the voltage measured was the potential fall across the cell. Since, however, the fixation of the halogens is strictly an anodic process, it is obviously better to determine the anode potential apart from the cathode potential, which, as shown by Specketer,* is strongly influenced by conditions of acidity and contact with air. The third electrode meets this requirement satisfactorily and the anodic potentials in the following experiments were all determined in this way.

Nature of the Electrolytic Medium.—In addition to the halide to be determined, especially when its amount is small, it was found best to have some other electrolyte present in the solution in order to facilitate the passage of the current. As has been shown by Foerster † and others, alkaline solutions favor the formation of oxidized halogen compounds, such as iodates. This would introduce an error into the determination, making the results too low, since the silver salts of the oxygen-halogen acids are appreciably soluble. In neutral solutions, the solution will become basic unless an amount of metal ions equivalent to the anions discharged is also separated on the cathode, as would be the case when zinc or cadmium salts constitute the electrolyte. This would increase the difficulty of estimating any silver transported to the cathode, since it would necessitate in every case an analysis of the deposit on this electrode. It is much better to be able to estimate the silver directly by gain in weight of the cathode, without having to make a chemical separation. Consequently acid solution appears to be the most favorable medium for the electrolysis.

Since the deposition potentials of the halogens increase with the dilution, we would seek as a solvent that solution which has the highest reaction potential with silver; for in this way the largest margin for the complete separation of the halogens would be available. But most acids show the same reaction potential,—·521 volts.‡ (See Table I.)

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* Zeitschr. Elecktroch., iv, 542. † Elektrochemie, 1905, p. 348 et seq.

‡ Referred to the hydrogen normal electrode as 0 volts. All potential measurements in this investigation have been referred to this standard.

TABLE I. *Reaction Potentials of Acids.*

Acids	Reaction Potentials
Sulphuric acid, ·5 molar	·521 volts
Nitric acid, 1·0 molar	·520
Phosphoric acid, ·33 molar	·521
Oxalic acid, ·5 molar	·520
Acetic acid, 1·0 molar	·522
Tartaric acid, ·5 molar	·521

This particular potential has been investigated in my preceding paper* and was found to be the potential at which silver begins to dissolve, irrespective of the nature of the anions present. For this reason it was given the name "solution potential of silver." Evidently there is a free choice among the acids in Table I, so far as margin for separation is concerned. However, 0·5 molar sulphuric acid was chosen, on account of its good conductivity and the fact that no intermediate solution would be necessary between the cell and the mercurous sulphate electrode.

Stirring—To prevent concentration polarization and to hasten the electrolysis, it is desirable that the electrolyte should be well stirred. Since, as shown in my previous paper,† the deposition potentials of the halogens appear to be independent of the nature of the stirring, whether by a current of gas or by other mechanical means, a rotating anode was adopted, as it affords the most effective stirring of the anode solution. Inasmuch as iodides in acid solution are readily oxidized by the air to free iodine, some of which (as shown by experiment) tends to be lost by volatilization, it is evident that the presence of air in the cell must be avoided. On account of its high density, carbon dioxide was used for this purpose. During all experiments a steady stream of the gas was introduced by a tube reaching almost to the surface of the solution, and allowed to escape through the space around the anode stem in the lid of the cell. In this way the space above the solution was kept filled with this gas.

Deposition Potentials of the Halogens.—Fig. 1 shows the relation between the concentration of the halogen ions and their deposition potentials. It is reproduced from fig. 5 of the preceding article, which has been so modified as to show only those lines which bear on the problem now being considered. As explained before, these lines are the "reaction potential curves" of the halogens, and were obtained by plotting the logarithms of the dilutions as abscissæ and the reaction potentials as ordinates. The figure accordingly shows in a

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* This Journal [4], xl, 281.

† Ibid.

comprehensive way, not only the behavior of the anode potential during an electrolysis, but also the value of the maximum potentials necessary for the separation and estimation of the halogens. In no case may the anode potential rise above ·521 volts, which has been defined as the "solution potential" of silver, for at that potential silver begins to dissolve.

The End Point in a Precipitation.—Speckter calculated by means of the Nernst formula the maximum potential that would be required for the complete separation of any halogen on the assumption that the final concentration of the halogen would be that of a saturated solution of the corresponding silver halide. Results obtained in this way are only approximate, because (1) the Nernst formula (as shown in the preceding article) does not express exactly the relation between electromotive force and concentration of the ion in the case of silver electrodes; and (2) the values of the solubilities of the silver halides are more or less uncertain.

Fig. 1.

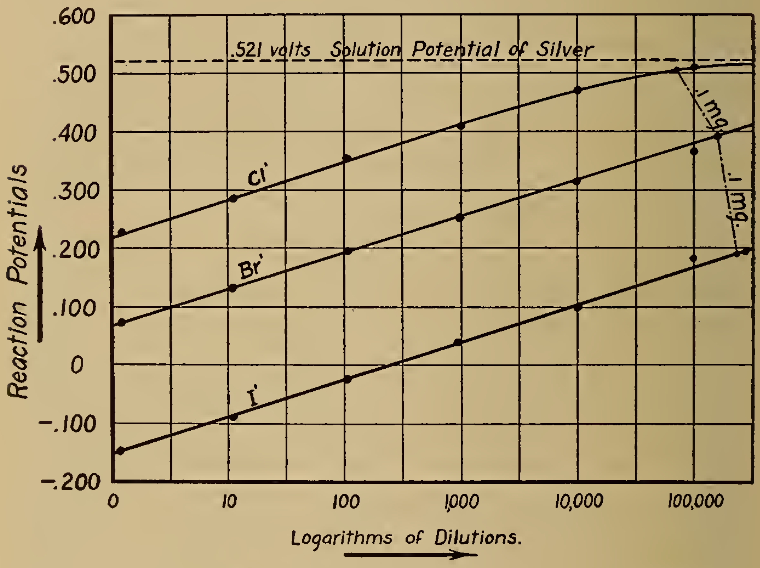

Fig. 1. Influence of concentration on the deposition potentials of the halogens.

Anodic reaction potentials of a saturated solution of a silver halide on silver electrodes coated with that halide are likewise more or less uncertain, owing to the difficulty of obtaining concordant results at the high dilutions involved.

The method used in this investigation for fixing the end point in a precipitation was to arbitrarily choose those points on the reaction potential curves (extrapolating when necessary) which correspond to 0·1 milligram—the ordinary limit of accuracy in analytical work. (See fig. 1.) This method promises greater accuracy than those mentioned above, since it depends only upon the probable assumption that the relation which is found to exist at low dilutions also exists at high dilutions. Only in the case of chlorine is the limit value of the anode potential doubtful, owing to the fact that its graph is not a straight line, as in the case with the other two halogens. This method gives the following results for volumes of 200^{cc}:

Maximum potential for chlorine	·505 volts
Maximum potential for bromine	·400 volts
Maximum potential for iodine	·190 volts

Apparatus.—Excepting the electrolytic cell, the apparatus was the same as that used in the determination of reaction potentials, as described in the preceding paper. The electrolytic cell (see fig. 2) was a glass cylinder 11^{cm} high and $8·7^{cm}$ in diameter. It was closed with a lid of wood fiber, through which the various connections were introduced. All electrical connections were insulated by glass tubing.

The anode (A in the figure) consisted of a frame of heavy silver wire whose cylindrical outer surface was covered with fine silver gauze. The diameter of this anode was $4·7^{cm}$, and the height (of the cylindrical portion) was $2·7^{cm}$. It was rotated with a speed of about 200 revolutions per minute. The anode before using was heavily coated with silver by making it the cathode in an ammoniacal silver solution to which ammonium oxalate had been added, as recommended by Gooch and Feiser.* It was then thoroughly washed and heated to about 500° in an electric oven, in order to make the deposit firm and adherent.

The cathode C was a piece of bright sheet platinum, 21×50^{mm}, provided with a stem of platinum wire ending in a loop, for convenient attachment to the cathode connection. To prevent swinging of the cathode by the rotating electrolyte, it was held in place by a glass rod whose lower end was drawn out into a fiber which was bent so as to form a hook, as shown in the figure. The cathode was weighed before and after each determination and any silver transported was estimated directly by difference.

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* This Journal, xxxi, 109.

Experimental Procedure.—200^{cc} of 0·5 molar sulphuric acid was introduced into the cell, and to this was added by means of a pipette a definite amount of potassium halide solution, whose halogen value had been carefully determined by precipitation with silver. The silver anode and the platinum cathode were weighed and put in place. After starting the motor which operated the rotating anode, the electrolytic cur-

FIG. 2.

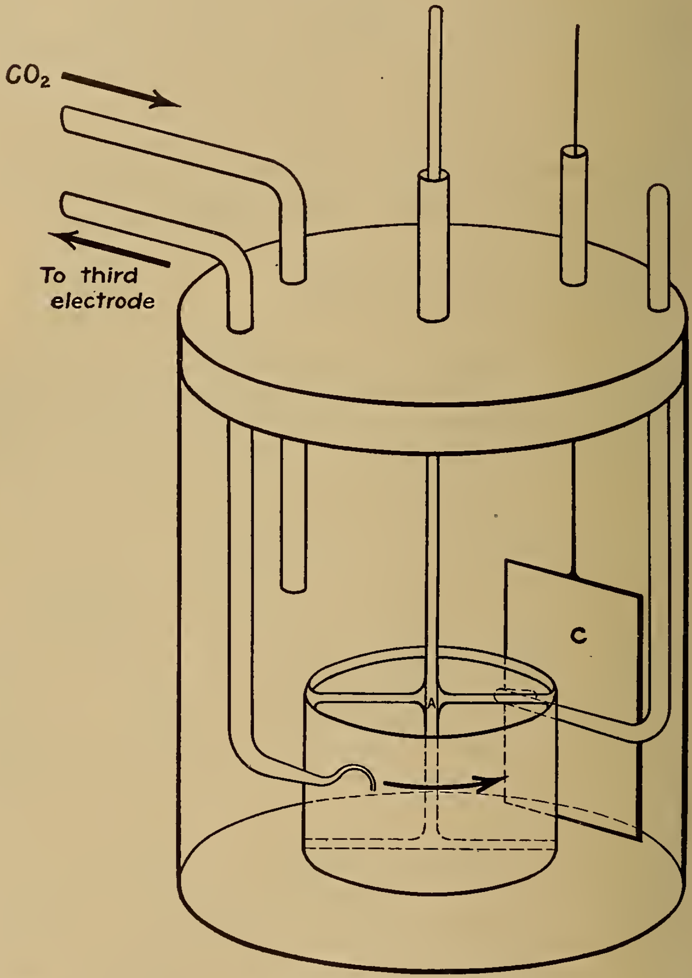

FIG. 2. Diagram of the electrolytic cell.

rent was turned on, the voltage at all times being adjusted so that the anode potential would conform to the limits mentioned before. In order to expedite the precipitation, the anode potential was brought at the start to a value just below the maximum. This potential requires constant attention and must be adjusted very frequently since it tends to rise very rapidly with the decrease of the halogen ions of the solution. The completion of the precipitation is indicated by the lack of deflection of the needle of a sensitive galvanometer. Conducted in this way, twenty to forty minutes are required for an electrolysis. The electrodes were then removed from the cell, carefully washed, and finally dried in an electric oven at about 500°. The gain in weight of the anode represents the halogen deposited.

Before making another determination the silver halide was reduced to metallic silver by making it the cathode in a dilute sodium hydroxide solution, using a tension of about two volts, and allowing the current to pass for a period of 50 to 60 minutes. The anode was then washed in dilute sulphuric acid, carefully rinsed in distilled water, and finally heated to about 500° in the electric oven for an hour or more. The silver after reduction is black in color and not very adherent, so that the anode must be handled very carefully to prevent loss. After heating it is white and firmly sintered together, so that there is no risk of mechanical loss in the subsequent manipulations.

Nature of the Haloid Deposit.—As long as the solution potential of silver is not exceeded, the haloid deposits on gauze anodes are quite adherent, and may be washed without fear of loss. If, however, this critical potential is exceeded, the silver halide seems to be formed in part out of actual contact with the metal, and for this reason does not adhere firmly. No such expedient as the alkaline tartrates used by Vortmann is necessary to make the deposit more adherent, if the proper attention is given to the anode potential. The precipitate is free from silver oxide, and hence does not require to be heated to a high temperature to effect the decomposition of this compound, as Vortmann, Gooch and Read, and Peters found necessary in their researches.

Influence of Current Strength.—Under the description of the procedure in an electrolysis, reference was made to the fact that the anodic potential must be watched continually, since it rises rapidly as the electrolysis progresses. To keep this potential from exceeding its critical value, the voltage of the electrolyzing current must be reduced from time to time, and this entails a corresponding diminution of current strength. Moreover, the current strength must be reduced, not in an arbitrary manner, but in the way the behavior of the anodic potential demands.

In a general way, the relation between current strength and time is represented in fig. 3, which is drawn from data obtained

FIG. 3.

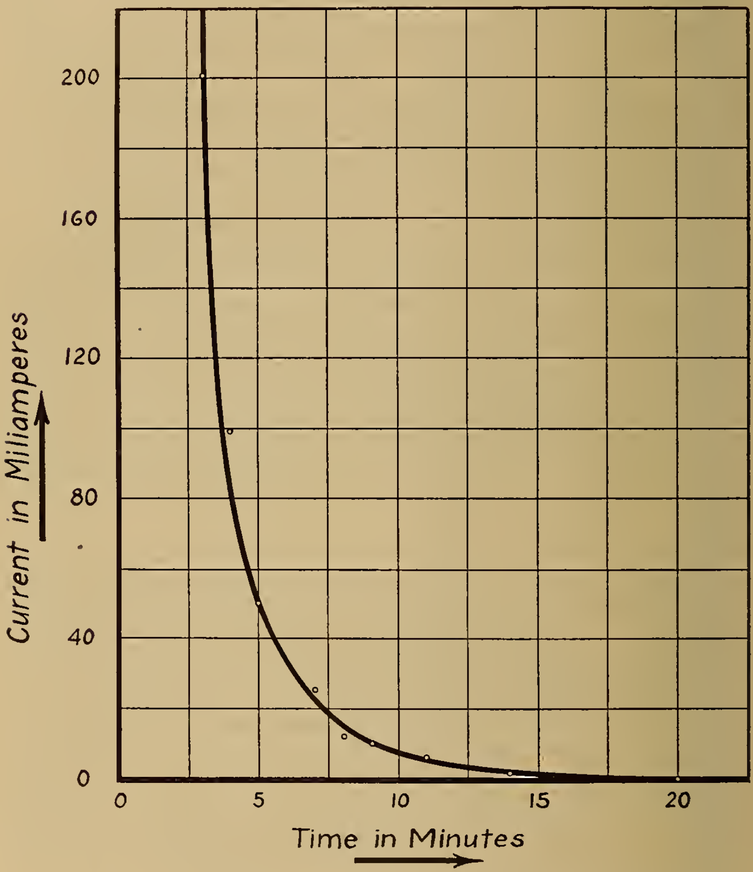

FIG. 3. Change of current strength during an electrolysis.

in a chlorine determination. The anodic potential was held at its maximum value by constant adjustment of the voltage, and from time to time readings of the current strength were made. It is seen that the current falls off very rapidly at first, but much more slowly after the halogen concentration has become low. This variation of the current strength with time depends on other influences, such as the concentration of the halogen anion, the resistance of the cell and external circuit, and the cathode potential. From this it is evident that any analytical method, in which it is sought to control the course of the electrolysis by regulation of the current strength without regard to the anodic potential,—as has been attempted by various investigators,— is, to say the least, inaccurate and uncertain.

Estimation of the Halogens.—Table II contains a summary of the results obtained in the estimation of the halogens. It should be stated that this table contains the results of all the determinations made in which the theoretical conditions were maintained. In a number of experiments the anodic potential, through lack of attention, rose too high, with the result that silver went into solution. Such experiments have been excluded from the table.

TABLE II. *Estimation of the Halogens.*
(Volume of Solution=205^{cc}.)

	Number of Exp.	Halogen taken grams	Halogen found grams	Error grams	Maximum anode poten'l volts
Iodine	1	·0620	·0618	—·0002	·205
Estimations	2	·0620	·0623	+·0003	·190
	3	·0620	·0617	—·0003	·190
	4	·0620	·0620	·0000	·190
	5	·0620	·0617	—·0003	·190
Bromine	6	·0396	·0386	—·0010	·440
Estimations	7	·0396	·0393	—·0003	·400
	8	·0396	·0396	·0000	·400
	9	·0396	·0393	—·0003	·400
	10	·0396	·0395	—·0001	·400
Chlorine	11	·0177	·0078	—·0099	·520
Estimations	12	·0177	·0166	—·0011	·520
	13	·0177	·0168	—·0009	·520
	14	·0177	·0164	—·0013	·520
	15	·0177	·0125	—·0052	·520
	16	·0177	·0162	—·0015	·520

The tendency towards low results in the iodine and bromine determinations is probably only accidental, and the results confirm the conclusions developed in the study of the conditions involved in the general process.

But in the case of the chlorine estimations, the deficiencies are not to be attributed to experimental error. In every case except one it was found that silver had gone into solution, and amounts varying from ·0003 to ·0010 grams in weight had been transported to the cathode. The exception was Exp. No. 15, in which the process was interrupted early, while the galvanometer still showed a minute current; and although no silver had dissolved, a considerable amount of chlorine remained in the solution. By reference to fig. 1 it will be seen that just such errors as these found in the chlorine estimations should be expected. Upon progressive dilution the deposition potential of chlorine approximates ·521 volts—the solution potential of silver,—and at that potential both the deposition of chlorine and the solution of silver will proceed simultaneously. That is, the anode potential of silver can not be raised high enough to deposit all of the chlorine without silver beginning to dissolve. For this reason, the estimation of chlorine on silver anodes can not be an accurate and trustworthy method.

Separation of the Halogens.—By reference to fig. 1 it will be seen that the halogens can not be separated electrolytically regardless of their concentrations. For example: For a volume of 200^{cc}, an anodic potential of ·190 volts is necessary to completely precipitate iodine on silver anodes. The same potential corresponds to a concentration of about ·0115 molar bromine. That is, if the bromine ions are present in greater concentration than this, there is a certain range of potential for which both iodine and bromine will be deposited simultaneously. For similar reasons chlorine must not be present in greater concentration than ·0014 molar if bromine is to be precipitated free from chlorine. In view of this small concentration, it is not surprising that Boettger and Kelly,* working more or less empirically, reported that bromine could not be separated from chlorine electrolytically. In the separation of iodine from chlorine, however, the concentration of the chlorine may be even higher than molar without its deposition potential overlapping the maximum potential for iodine.

Evidently, the approximate bromine and chlorine concentrations must be known before a separation may be attempted. If they exceed the above limits, proper dilution must be made. It should be remembered, however, that dilution is always made at the expense of accuracy in the determination of the halogen of low concentration.

Analytical Separations.—The conclusions drawn above as to the necessary conditions for the separation of the halogens were applied experimentally in a number of determinations, with the results indicated in Table III.

In Exp. No. 23 the anode potential rose too high and some bromine was deposited, which accounts for the positive error.

In Exp. No. 32, the chlorine concentration was ·0024 molar —considerably higher than ·0014 molar, which was taken to be the maximum chlorine concentration allowable for a complete

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* Verh. Ges. deutsch. Aertze, 1913 (1914), ii, 361.

TABLE III. *Separation of the Halogens.*

(Volume of Solution = 210^{cc}.)

Iodine from Chlorine.

Number of Exp.	Chlorine conc. moles	Maximum anode pot. volts	Iodine taken grams	Iodine found grams	Error grams
17	·0046	·190	·0620	·0617	—·0003
18	·0046	·190	·0620	·0619	—·0001
19	·0046	·190	·0620	·0619	—·0001
20	·0046	·190	·0620	·0618	—·0002
21	·0046	·190	·0620	·0621	+·0001

Iodine from Bromine.

Number of Exp.	Bromine conc. moles	Maximum anode pot. volts	Iodine taken grams	Iodine found grms	Error grams
22	·0046	·190	·0620	·0623	+·0003
23	·0046	·213	·0620	·0628	+·0008
24	·0046	·190	·0620	·0621	+·0001
25	·0046	·190	·0620	·0620	0000
26	·0046	·190	·0620	·0619	—·0001

Bromine from Chlorine.

Number of Exp.	Chlorine conc. moles	Maximum anode pot. volts	Bromine taken grams	Bromine found grams	Error grams
27	·0010	·400	·0396	·0401	+·0005
28	·0010	·400	·0396	·0389	—·0007
29	·0010	·400	·0396	·0394	—·0002
30	·0010	·400	·0396	·0395	—·0001
31	·0010	·400	·0396	·0393	—·0003
32	·0024	·400	·0396	·0469	+·0073

separation. Consequently, some chlorine was deposited along with bromine in the later stages of the electrolysis. It is interesting to note that the positive error of ·0073 grams agrees closely with the error that might be expected from theoretical considerations. The excess of the chlorine concentration over ·0014 molar, the limit found above, was ·001 molar. This, for 210^{cc}, the volume of the solution in this experiment, is equivalent to ·0075 grams, which is practically identical with the experimental error.

These results confirm in a forceful way the conclusions drawn above as to the effects of concentration in the electrolytic separation of the halogens.

Analytical Applications.—The processes just described are not offered as analytical methods. If has been the purpose of the writer throughout this investigation merely to determine the conditions which must be observed in the electrolytic deposition of the halogens on silver, and not to perfect any analytical procedure. Furthermore, the methods which have been used in this work will hardly commend themselves to the practical analyst. The apparatus is too elaborate, and the manipulation is unsatisfactory in that it demands thorough familiarity with this unusual kind of work, not to mention the fact that the constant adjusting of the anode potential precludes the carrying on of other experiments at the same time. However, it is hoped that this work will make clear what is possible and what is impossible in the quantitative separation and estimation of the halogens by means of a silver anode.

Summary.

The conclusions reached in this study of the determination of the halogens by means of silver anodes may be briefly stated as follows:

(1) The anodic potential must be known at every stage of the electrolysis, so that the maximum value of the potential for that particular process may not be exceeded.

(2) In no case may the anodic potential rise above ·521 volts, since silver dissolves at the potential.

(3) The course of the electrolysis can not be properly controlled by the regulation of the current, independent of the anode potential.

(4) Chlorine can not be satisfactorily estimated by electrolytic precipitation on silver, since the anodic potential required for its complete deposition is approximately the same as that at which silver dissolves.

(5) Quantitative separation of the halogens is possible only within certain definite limits of concentration.

ART. XXX.—*Nephelite Syenites of Haliburton County, Ontario*; by WILBUR G. FOYE.

Part I. Two differentiated Laccoliths of Nephelite Syenite in Glamorgan and Monmouth Townships.
  Introduction.
    A. Gooderham Laccolith.
      General Geology.
      Petrography:
        1. Red syenite.
        2. Schistose canadite.
        3. Nephelite pegmatite.
        4. Kaolinized contact rock.
    B. Crescentic Laccolith near Tory Hill.
      General Geology.
      Petrography:
        1. Garnet-pyroxene contact rock.
        2. Hornblende-nephelite rock.
        3. Monmouthite.
        4. Biotite-nephelite rock.
        5. Pegmatitic nephelite syenite.
Part II. Suggestion concerning the Origin of the Nephelite Syenites.
  Smyth's Theory.
  Confirmatory Evidence.
  Pneumatolytic Metamorphism of the Limestone to Amphibolite.
  Nature of the Solutions Introduced into the Limestones.
  Quantitative Importance of this Alteration.
  Origin of the Fluids Producing the Amphibolites.
    a. Segregation by juvenile gases.
    b. Interaction of the granite magma and limestone.
  Emplacement of the Laurentian Granite and Origin of Lit-par-lit Structure.
  Genetic Relations of Amphibolite and Nephelite Syenite.
  Field Facts Showing Desilication of the Granite and Origin of Soda-rich minerals.
  Conclusions.

PART I.

INTRODUCTION.

The laccoliths of nephelite syenite, described in this paper, are located in Haliburton County, Central Ontario. They are reached by way of the Central Ontario Railroad from Trenton and the Irondale, Bancroft and Ottawa Railroad, which connects with the Central Ontario Railroad at Bancroft. One of the laccoliths lies southeast of the village of Gooderham; the other lies southwest of Tory Hill. Messrs. F. D. Adams and A. E. Barlow have described the general geology of this area in their memoir, "The Geology of the Haliburton-Bancroft Area, Ontario."*

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*F. D. Adams and A. E. Barlow, "The Geology of the Haliburton-Bancroft Area, Ontario," Memoir No. 6, Canada Geol. Surv., 1910.

Fig. 1.

Fig. 1. Sketch Map of the District about Gooderham, Glamorgan Township, Haliburton County, Ontario. A=Gooderham laccolith. B=Crescentic laccolith. *a*=Nephelite syenite, *b*=Granite, *c*=Limestone, *d*=Amphibolitic limestone, *e*=Pyroxenite, *f*=Gabbro.

A. THE GOODERHAM LACCOLITH.

The nephelite syenite laccolith indicated on the accompanying sketch map by the letter A is situated in Glamorgan township near the village of Gooderham. It is one of a number of nephelite syenite bodies lying in a syncline of limestone between large areas of Laurentian gneiss.

General Geology.

The accompanying sketch map (fig. 1) shows the general geology of the area immediately adjacent to the Gooderham nephelite syenite laccolith. Limestone surrounds the body on all sides. This limestone is cut by many granite pegmatite dikes and has lenses of amphibolite associated with it.

The nephelite syenite body consists of three principal rock types. These are: (1) red syenite (umptekite), (2) nephelite syenite (canadite), and (3) nephelite pegmatite. A north-south cross section of the body shows the rock relationships (fig. 2).

FIG. 2.

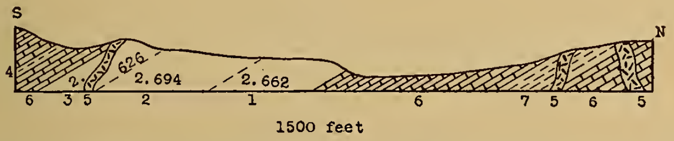

FIG. 2. Cross-section of the Gooderham Laccolith.
1=Red syenite, 2=Schistose canadite, 3=Nephelite pegmatite, 4=Amphibolite, 5=Granite pegmatite, 6=Limestone, 7=Amphibolitic limestone.
(The figures within the sketch give the specific gravities of the several rock types.)

The specific gravities of the several rock types are indicated by numbers on the section. The mass of nephelite pegmatite is unduly large for the size of the laccolith. It cannot be doubted that the syenite magma was surcharged with pneumatolytic gases at the time of its emplacement. The activity of the gases is held to be largely responsible for the differentiation of this body. The nephelite pegmatite rests on the denser canadite but the red syenite at the base has a lower density than the overlying canadite. At other localities the red syenite cuts the canadite and again it is transitional to this rock. The contact in this instance is covered by drift.

It is quite possible that the red syenite was intruded after the nephelite syenite had differentiated into nephelite pegmatite and canadite. This fact may account for the seeming lack of gravitative control in the differentiation of this laccolith. However, pneumatolytic transfer of the elements of the pegmatite towards the roof of the body was the prime factor in the differentiation.

The limestone, north of the laccolith, has been eroded from beneath the red syenite. The latter rock has broken down and has formed a talus-slope which conceals the contact of the two rocks. Drift likewise covers the contact of the canadite with the nephelite pegmatite.

The contact of the nephelite pegmatite with the overlying limestone is marked by a kaolinized zone a foot or two wide. Coarsely crystalline calcite is included in blebs in the kaolinized material. Scapolite, apple-green apatite, and some pyrrhotite are also associated with this rock. With increase of calcite the kaolinized zone passes into the normal limestone.

Fig. 3.

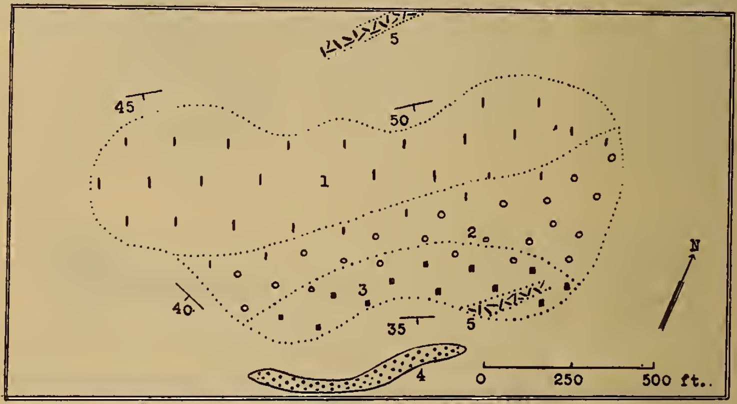

Fig. 3. Distribution of the several rock types in the Gooderham Laccolith. 1=Red syenite, 2=Schistose canadite, 3=Nephelite pegmatite, 4=Amphibolite, 5=Granite pegmatite.

Petrography of the Gooderham Laccolith.

Figure 3 shows the general distribution of the rock types associated with the Gooderham laccolith.

1. *Red Syenite.*

Macroscopic description.—This rock is reddish gray in color, rather fine in grain and even-textured. It is composed predominantly of pink feldspar in granules 1 mm. in diameter. Occasional crystals of white feldspar are likewise present. Flecks of black mica and some hornblende are evenly disseminated through the rock and are arranged in such a way as to produce a vague schistosity. The rock is very fresh, breaks with an irregular fracture, and is of average weight.

Microscopic description.—The red syenite resembles very closely the rock described by Adams and Barlow* as umptekite. A rough estimate of the mineral composition of the rock is:

Orthoclase	20 per cent.
Microcline	10
Albite	20
Microcline-albite microperthite	33
Biotite	12
Hornblende	0·75
Calcite	4·
Zircon	·25
	100·00

The *biotite* is olive-green in color.

The *hornblende* is also olive-green and extinguishes at a small angle.

The *albite* has the approximate composition Ab_9An_1.

Calcite is present as irregular grains of primary origin.

The rock has an allotriomorphic granular texture.

2. *Schistose Canadite.*

Macroscopic description.—The typical nephelite syenite of the Haliburton area, of which this rock is an example, has been called by Quensel,† canadite. It is distinguished from the usual nephelite syenite by the predominance of albite instead of a potash feldspar. It is a light gray rock, occasionally dotted with pink. It is medium and even-grained.

Biotite and feldspar are about equal in amount and form the larger portion of the rock. The gray platy feldspar is sometimes replaced by a pink variety. The rock breaks with an irregular fracture and appears quite fresh to the unaided eye.

Microscopic description.—A thin section of this rock shows that it is composed of calcite, biotite, microperthite, and nephelite. These minerals crystallized approximately in the order named. They are present in the following proportions by weight:

Albite	79·34 per cent
Microperthite	3·03
Nephelite	3·27
Biotite	11·94
Calcite	2·42
	100·00

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*F. D. Adams and A. E. Barlow, Memoir No. 6, Canada Geol. Surv., 1910, p. 321.

†P. D. Quensel, Bull. Geol. Inst. of Upsala, vol. xii, p. 135, 1914.

The *biotite* is nearly black in color.

The *albite* corresponds to the mixture ($Ab_{96}An_4$).

The *calcite* occurs as rounded grains between the other minerals. It is evidently primary in origin.

The *microcline* is closely associated with the nephelite and occurs also as resorbed blebs in the albite. The evidence points to the fact that the earlier found microcline was unstable and that the increasing amount of soda in the magma allowed albite to take its place.

The rock is hypidiomorphic, sometimes poikilitic, in texture.

Chemical composition.—No chemical analysis of the particular rock described above is available. This rock is, however, practically the same as one described by Adams and Barlow* from the adjacent township of Monmouth. The analysis of the latter rock is as follows :—

SiO_2	51·58 per cent
TiO_2	·35
Al_2O_3	19·40
Fe_2O_3	4·26
FeO	5·29
MgO	·49
MnO	·20
CaO	3·64
Na_2O	7·49
K_2O	4·23
P_2O_5	·15
CO_2	1·53
H_2O	1·02
	99·59

The calculated norm is :—

Orthoclase	25·02 per cent
Albite	38·84
Anorthite	6·67
Nephelite	15·50
Diopside	·90
Olivine	5·05
Ilmenite	·73
Magnetite	6·15
Apatite	·34
Calcite	3·45
Water	1·02
	99·67

The rock occupies the following position in the "norm" classification :

Class II ....Dosalane
Order 6 ....Nogare
Rang 2..............Essexase
Sub-rang 4............Essexose

3. *Nephelite Pegmatite.*

Macroscopic description.—Nephelite in irregular, anhedral crystals 4–5 cm. long and 3 cm. wide composes the larger portion of the nephelite pegmatite. Masses of calcite which show parting on $-\frac{1}{2}R$ are found between the nephelite crystals. A few

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* F. D. Adams and A. E. Barlow, Memoir No. 6, Canada Geol. Surv. 1910, pp. 262-264.

masses of scapolite, 2–3 cm. wide, are irregularly distributed through the rock, and, here and there, a bit of pyrrhotite is seen.

A delicate pinkish white mica is also present and areas of sodalite which fade gradually into the nephelite.

The rock is allotriomorphic granular in structure, breaks with an irregular, subconchoidal fracture and is very fresh in appearance.

Microscopic description.—The microscope shows that nephelite, sodalite and calcite predominate in the pegmatite.

The *nephelite* is in amoeboid forms extending into the albite. The evidence seems to show that whereas albite replaced microcline in the canadite, due to the increasing amounts of soda in the syenite magma, in this case the albite was replaced by nephelite for a like reason.

Sodalite, also, replaces the nephelite and wraps about the grains of the latter mineral in irregular, amoeboid granules.

The *albite* is practically free from lime. It is present in anhedral granules with threads of calcite intergrown along its twinning planes.

The order of crystallization is muscovite, calcite, albite, nephelite, sodalite.

4. *Kaolinized Contact Rock.*

Macroscopic description.—There is a gradual transition from the nephelite pegmatite to the limestone along the upper contact of the nephelite syenite laccolith. The nephelite pegmatite is gradually altered to kaolin and calcite becomes more abundant until it completely replaces the nephelite rock. Biotite and apatite with minute red garnets appear, together with large masses of granular scapolite and albite.

Twenty per cent of the rock is nephelite. This mineral is altering to kaolin, which forms fifty per cent of the rock. Calcite occurs in resorped grains in the nephelite and kaolin.

Apatite occurs as prismatic crystals 1–2 cm. long and a centimeter wide. The mineral is a light apple-green in color.

The kaolinized and the fresh pegmatite are equally exposed to the processes of weathering. The kaolin is, therefore, probably not due to secular alteration. The presence of fresh calcite within the kaolinized rock, also, would indicate that secular weathering has not progressed very far and that the solutions which effected the kaolinization did not contain acids capable of corroding the calcite. It is believed that the kaolinization was produced by carbonated waters during the latter part of the period of pneumatolytic action which produced the nephelite pegmatite.

Microscopic description.—The thin section of the kaolinized rock shows only a few features not discernible in the hand specimen.

The *calcite* is present in large cleavage sections set in a matrix of fine, fibrous, decomposition products consisting of kaolin and muscovite.

The *muscovite* often shows rosette arrangement.

FIG. 4.

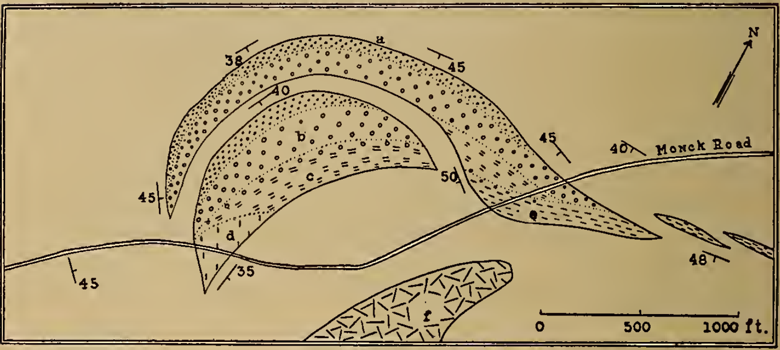

FIG. 4. Distribution of the several rock types in the Crescentic Laccolith of Tory Hill.

a=Garnet-pyroxene rock, b=Hornblende-nephelite rock, c=Monmouthite, d=Pegmatitic nephelite syenite, e=Biotite-nephelite rock, f=Granite pegmatite.

B. THE CRESCENTIC LACCOLITH NEAR TORY HILL.

General Geology.

This laccolith is indicated on the accompanying sketch map (fig. 1) by the letter B; fig. 4 shows the general distribution of the rocks associated with the body.

There are two parts to the laccolith. These are separated by limestone. Limestone surrounds the mass on all sides and dips away conformably to the contact. A massive, granite-pegmatite dike forms a hill 200 yards across, south of the body.

A basic nephelite rock, consisting predominantly of garnet and pyroxene, is found at the lower or northern contact of the laccolith. The contact occurs at the top of a steep hill. The garnet-pyroxene rock forms a zone from four to eight feet in thickness. It grades into another type, still basic, but containing nodules of nephelite and some hornblende. The latter rock is transitional to monmouthite, which was first described from this locality.*

A valley intervenes between the northern and southern portions of the crescentic body. Masses of graphite occur within this valley. They are sometimes found in the limestone but more often are associated with the nephelite syenite.

The rocks of the southern portion of the body occur in the same order as those of the northern portion. A coarse-grained, almost pegmatitic variety not found in the northern portion, forms, however, a considerable area south of the Monck Road.

The dips and strikes of the surrounding limestones and the fact that the limestone passes beneath the northern border of this body are clear indications of its laccolithic character.

Fig. 5.

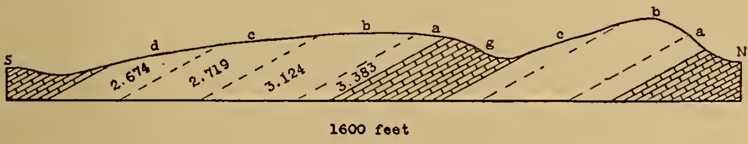

Fig. 5. Cross-section of the Crescentic Laccolith near Tory Hill. *a*=Garnet-pyroxene rock, *b* =Hornblende-nephelite rock, *c*=Monmouthite, *d*=Pegmatitic nephelite syenite, *g*=Limestone.

Figure 5 is a north-south section of the laccolith. The figures within the section indicate the specific gravities of the rock at 20° C. These figures show that gravity controls the differentiation of this mass. The rocks are all nephelite types and red syenite is not associated with them. This fact strengthens the opinion that the red syenite of the Gooderham laccolith was intruded after the nephelite types had differentiated, as indicated in the description of that body.

Petrography of the Crescentic Laccolith.

Figure 4 shows the distribution of the several rock types associated with the crescentic laccolith.

1. *Pyroxene-Garnet Contact Rock.*

Macroscopic description.—The pyroxene-garnet contact rock is transitional to the overlying hornblende-nephelite rock. It is reddish-black in color and is composed of greenish-black

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* F. D. Adams and A. E. Barlow, Mem. No. 6, Canada Geol. Surv., 1910, pp. 274–277.

pyroxene granules a half a millimeter in diameter, associated with red garnet in granules of the same size. Occasionally, large crystals of pyroxene, from 1 to 5 cm. long and a centimeter or more wide, are present. The rock is mottled with grayish-white areas of calcite and albite which have a border of red garnet against the pyroxene.

Microscopic description.—The following minerals in approximately the given proportions are found in the contact rock:—

Calcite	25 per cent
Pyroxene	34
Garnet	37
Albite	3
	100

Calcite, besides forming with pyroxene and garnet a groundmass of mosaic texture, occurs as minute blebs in the larger pyroxene crystals.

The *garnet* is often found as euhedral crystals.

The *pyroxene* is apple-green in color and extinguishes 36–37° on (110).

The texture of the rock is allotriomorphic granular.

Chemical description.—The following analysis is quoted from Adams and Barlow.* The garnet-pyroxene rock just described is more basic than the rock described by the above writers as type I. The latter rock is intermediate in composition between the garnet-pyroxene and the hornblende-nephelite rock. The hornblende-nephelite rock corresponds closely to their type II.

Analysis of type I of Adams and Barlow.

SiO_2	43·67 per cent
TiO_2	0·78
Al_2O_3	20·91
Fe_2O_3	3·54
FeO	8·01
MgO	1·46
MnO	0·05
CaO	7·37
Na_2O	6·73
K_2O	2·25
P_2O_5	0·11
CO_2	2·37
H_2O	2·52
	99·77

The calculated norm is :—

Orthoclase	12·79 per cent
Albite	22·01
Anorthite	20·29
Nephelite	19·03
Olivine	10·58
Ilmenite	1·52
Magnetite	5·10
Apatite	·34
Calcite	5·41
	97·07
Water	2·52
	99·59

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* F. D. Adams and A. E. Barlow, Memoir No. 6, Canada Geol. Surv. 1910, pp. 269–270.

Its position in the norm classification is therefore :—

Class III	Dosalane
Order 6	Norgare
Rang 2	Essexase (near Salemase)
Sub-rang 4	Essexose

2. *Hornblende-Nephelite Rock.*

Macroscopic description.—The hornblende-nephelite rock is mottled black and white and contains occasional grains of garnet from 1 to 5 mm. in diameter.

The jet black hornblende granules are arranged in irregular masses or lines with bits of feldspar or nephelite lying between them.

The nephelite has the creamy white color it assumes when slightly decomposed.

Microscopic description.—The thin section cut from this rock does not correctly represent the relative amounts of its constituent minerals. A comparison of the section and the hand specimen gave the following approximate percentage composition :—

Nephelite	30·0 per cent
Albite	7·0
Hornblende	30·0
Pyroxene	20·0
Garnet	7·5
Calcite	5·0
Apatite	·5
	100·0

The *nephelite* occurs as large irregular grains.

The *albite* is in minute rounded crystals, within or adjacent to the nephelite.

The *hornblende* is deeply pleochroic, dark bluish green to brown.

The *pyroxene* is apple-green in color. It is much shattered and the cracks are healed by an epidote, or, sometimes, garnet.

The rock as a whole shows granulations under pressure.

Chemical description.—Adams and Barlow give the following analysis for their type II, which is approximately the same as this rock :—

SiO_2	42·72 per cent
TiO_2	0·38
Al_2O_3	25·08
Fe_2O_3	2·00
FeO	4·36
MgO	·97
MnO	·16
CaO	6·92
Na_2O	11·02
K_2O	2·69
P_2O_5	·19
CO_2	2·99
H_2O	·88
	100·36

The calculated norm is :—

Orthoclase	15·57 per cent
Albite	7·34
Anorthite	10·80
Nephelite	46·58
Diopside	3·08
Olivine	5·10
Ilmenite	·76
Magnetite	2·78
Apatite	·34
Calcite	6·80
	99·15

Its position in the norm classification is :—

Class II	Dosalane
Order 7	Italare
Rang 2	Vulturase
Sub-rang 4	Vulturose

3. *Monmouthite.*

Macroscopic description.—Monmouthite was first described from the laccolith now under discussion.* The rock which is about to be described resembles the type monmouthite but does not contain hornblende (hastingsite) or cancrinite. The original type is very rare in this locality.

The rock is bluish-gray in color, medium-grained and somewhat schistose. It is flecked with minute bits of black mica (1–2 mm. in diameter) which are arranged in sub-parallel layers.

Microscopic description.—The minerals found in this rock, arranged according to their proportions by weight, are :—

Nephelite	56·68 per cent
Scapolite	10·18
Biotite	22·50
Albite	9·25
Kaolin	1·02
Calcite	·37
	100·00

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* F. D. Adams, this Journal, (4), vol. xvii, pp. 272-276, 1904.

A small amount of zoisite is also present. Adams states that the specific gravity of the *scapolite* is 2·711, which shows that it is near the meionite end of the scapolite series.

Biotite is closely associated with the scapolite. When biotite appears, nephelite disappears and scapolite or albite takes its place.

The *kaolin* is largely the decomposition product of the nephelite.

Chemical description.—The following is the analysis of the type monmouthite as given by Adams and Barlow:*

SiO_2	39·74 per cent
TiO_2	0·13
Al_2O_3	30·59
Fe_2O_3	·44
FeO	2·19
MgO	·60
MnO	·03
CaO	5·75
Na_2O	13·25
K_2O	3·88
CO_2	2·17
SO_3	tr
Cl	0·02
S	0·07
H_2O	1·00
	99·86

The calculated norm is :—

Anorthite	12·51 per cent
Nephelite	67·72
Leucite	8·28
Olivine	3·70
Akermanite	·40
Magnetite	·70
Ilmenite	·30
Pyrite	·14
Calcite	4·92
	98·07
Water	1·00
	99·07

Its position in the norm classification is as follows:—

Class 1	Persalane
Order 8	Ontarare
Range 2	Monmouthase
Sub-rang 4	Monmouthose

4. *Schistose Nephelite-Biotite Rock.*

Macroscopic description.—The eastern end of the northern portion of the crescentic laccolith is composed of a bluish-black, medium-grained and very schistose rock which is largely made up of biotite. The biotite is in crenulated layers which form wavy lines across the rock. Between these layers are lenses of gray and pink feldspar and nephelite from a centimeter to a centimeter and a half in length and from 8 to 10 mm. wide.

Microscopic description.—An estimate of the percentage amounts of the several minerals composing the rock, made by

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* F. D. Adams and A. E. Barlow, Memoir No. 6, Canada Geol. Surv., 1910, p. 276.

comparing the thin-section with the hand specimen, gave the following result:—

Albite	45 per cent
Nephelite	10
Biotite	30
Orthoclase	10
Pyrrhotite	2
Calcite	3
	100

The twin lamellæ of the *albite* are much contorted. The compressive stresses were able to fracture the minerals of the rock but recrystallization is not found.

Nephelite occurs as amoeboid grains between the albite crystals. It is, also, included in the albite.

The *orthoclase* is in allotriomorphic crystals and is usually associated with biotite.

No chemical analysis of this rock type is available.

5. *Pegmatite-Nephelite Syenite.*

Macroscopic description.—The pegmatitic facies of the crescentic laccolith is coarse-grained but is not as rich in nephelite as the nephelite pegmatite of the Gooderham body. It is light bluish-gray in color and is mottled with patches of black.

The light-colored minerals are feldspar and nephelite. They occur in allotriomorphic crystals from 2 to 3 cm. long and from 1 to 2 cm. wide. Grains of hornblende are grouped in masses from 2 to 3 cm. in diameter. These sometimes show a vague schistose arrangement.

Titanite occurs in crystals 2 cm. long and a centimeter wide. Apatite is present in long slender needles which are light-green in color. Bits of pyrrhotite are disseminated through the rock and sodalite may occasionally be seen.

Microscopic description.—The following minerals compose the rock in the given proportions by weight:—

Microperthite	59·02 per cent
Albite	12·24
Nephelite	21·42
Hornblende	4·40
Calcite	2·40
Titanite	·52
	100·00

Sodalite was not shown in the slide examined.

The *nephelite* often surrounds the albite and has apparently replaced that mineral. A border of albite sometimes intervenes between the nephelite and microperthite.

The *hornblende* resembles hastingsite.

The *calcite* is primary and occurs as rounded grains in the hornblende or between the hornblende and nephelite crystals.

No analysis of this type is obtainable.

PART II.

SUGGESTION CONCERNING THE ORIGIN OF NEPHELITE SYENITES.

Professor C. H. Smyth, Jr.,* has suggested that the nephelite syenites are segregated from a primary magma by means of pneumatolytic gases. The pneumatolytic origin of nephelite and sodalite has been advocated by a number of writers. Mierisch† and Lacroix‡ found that these minerals were sublimation products within the cavities of limestone bombs from Monte Somma. Lacroix states:—"The veinlets of orthoclase, sodalite, etc., traversing a doleritic leucite-tephroite, recall in a striking manner veinlets of nephelite aplite which traverse the essexites and nephelite gabbros of Madagascar, Brazil, etc."

Brögger,§ in his study of the nephelite pegmatites of Norway, found that nephelite was frequently altered to sodalite and infers that the latter mineral was the result of the action of hot sodium chloride solutions. Lacroix‖ intimates that chlorine and fluorine were influential in the formation of sodalite in the nephelite syenites of the Los Archipelago. F. W. Clarke¶ considered the sodalite of the nephelite syenite type, litchfieldite, to have been formed at the expense of nephelite.

J. Lemberg** produced sodalite from nephelite powder by allowing it to stand six months on a water bath at 100° C. in a 20 per cent solution of sodium chloride.

The accompanying black and white sketch (fig. 6) shows the vein-like aspect of the sodalite in a nephelite syenite from Ice River, British Columbia.†† It would be difficult to disprove the pneumatolytic origin of the mineral in this case.

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* C. H. Smyth, Jr., this Journal, (4), vol. xxxvi, pp. 33–46, 1913.

† Bruno Mierisch, Tscherm. Mitt., vol. viii, p. 188, 1887–88.

‡ A. Lacroix, Mus. d'Hist. Nat. (Paris), Nouv. Arch., (4), vol. ix, p. 101–102, 1907.

§ W. C. Brögger, Zs. Kryst., vol. xvi, p. 167, 1890.

‖ A. Lacroix, Mus. d'Hist. Nat., (5), vol. iii, p. 98.

¶ F. W. Clarke, this Journal, (3), vol. xxxi, p. 268.

** S. Lemberg, Zs. d. d. Geol. Gesel., vol. xxxv, p. 582, 1883.

†† This slab may be seen in the geological laboratory of Harvard University.

The close association of nephelite syenites with granite pegmatites, in the Haliburton area, indicates that they originated during the pneumatolytic stage of the intrusion of the Laurentian granite. The parent magma of the Gooderham nephelite syenite laccolith must have been especially charged with pneumatolytic gases since the amount of nephelite pegmatite associated with the body is unduly large.

Fig. 6.

Fig. 6. Tracing of the sodalite areas of a polished slab of sodalite-syenite from the Ice River district, British Columbia.

Many instances have been given in the discussion of the Gooderham and Tory Hill laccoliths of the replacement of microcline by albite, of albite by nephelite, and in certain cases of nephelite by sodalite. The accompanying microphotographs illustrate this point (fig. 7). It is believed that these replacements show that a magma, from which microcline was first capable of crystallizing, was gradually enriched in soda, until first albite, then nephelite, and, finally in the extreme cases of

FIG. 7*a*.

FIG. 7*a*. Albite and microcline associated with nephelite. The microcline has a border of albite against the nephelite (x 24).

FIG. 7*b*.

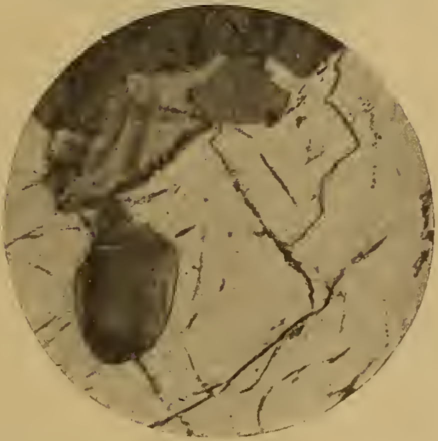

FIG. 7*b*. Microcline resorped by nephelite (x 48).

the nephelite pegmatites, sodalite was the stable product of crystallization.

How these soda solutions were introduced into the magma is not definitely known. Nevertheless, it is reasonable to suppose that the so-called pneumatolytic elements now associated with the nephelite syenites were the effective means of transportation. The minerals of the nephelite pegmatite of the Gooderham laccolith are nephelite, albite, sodalite, scapolite, apatite, calcite, titanite, and pyrrhotite. Chlorine is associated with three of these minerals, carbon dioxide with one, phosphorus with one, and sulphur with one. These elements are believed to have been active in producing the nephelite syenites.

Fig. 7c.

Fig. 7c. Albite resorped by nephelite (x 48).

Figs. 7a, b, c. Microphotographs of the nephelite pegmatite from the crescentic body near Tory Hill.

The writer is firmly of the opinion that Professor Smyth is correct and that many lines of evidence lead to the conclusion that the nephelite and sodalite rocks are associated with the pneumatolytic state of igneous activity and are produced by gaseous transfer of their elements.

Recently while studying the chemical composition of the amphibolites of Haliburton County, which Adams and Barlow* have shown were derived from limestone, it was impressed on

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* F. D. Adams and A. E. Barlow, Memoir No. 6, Canada Geol. Surv. 1910, pp. 103–111 ; also F. D. Adams, Journ. of Geol., vol. xvii, p. 1–16, 1909.

the writer that the origin of these rocks was perhaps closely associated with the origin of the nephelite syenites. Column 1 of Table I gives the composition of a typical amphibolite derived from limestone. Column 2 is the analysis of an average limestone from the same locality.

TABLE I.

	1	2
SiO_2	50·00	2·27
TiO_2	0·82	----
Al_2O_3	18·84	----
Fe_2O_3	2·57	1·31
FeO	5·51	----
MgO	4·63	3·20
MnO	0·08	----
CaO	10·65	49·88
Na_2O	4·48	----
K_2O	1·18	----
CO_2	0·10	42·73
S	0·03	----
Cl	0·10	----
H_2O	1·00	----
	99·97	99·39

It will be seen that the limestone lost in the process of its transformation to amphibolite 39·2 per cent of lime and 42·6 per cent of carbon dioxide. On the other hand, it gained 47·7 per cent of silica, 19 per cent of alumina, 6·8 per cent of iron oxide, 1·4 per cent of magnesia, 4·5 per cent of soda, and 1·2 per cent of potash, beside other minor elements.

Table II shows the added oxides and the same oxides from the type canadite of the Haliburton area (see page 418) recalculated to 100 per cent.

TABLE II.

	1 Amphibolite from limestone	2 Nephelite syenite
SiO_2	60·4	56·2
Al_2O_3	22·8	20·6
Fe_2O_3 & FeO	8·8	10·8
MgO	1·7	0·5
Na_2O	5·0	7·6
K_2O	1·3	4·3
	100·0	100·0

If the alkalies are neglected, the difference between the percentages of the other elements are not greater than those registered by the varying types of the nephelite syenites.

Column 1 of Table II shows beyond doubt that solutions high in alumina and relatively high in soda were introduced into the limestone and that, to a degree, these solutions were similar to the material which went to form the nephelite syenites.

To one who has studied the Haliburton district closely, it appears very clear that the processes which Adams and Barlow described have actually taken place and that amphibolites have been derived on a large scale from limestone. All steps in this process are continually met with. The limestone is first impregnated with diopside crystals. Then scapolite and diopside appear side by side in a matrix of calcite. Later diopside and feldspar are developed, and finally the diopside is replaced by hornblende and the transformation is complete.

The evidence of this transformation was accepted by the International Committee on Pre-Cambrian nomenclature.* The following statement is quoted from their report:

"The committee are of the opinion that the evidence is indisputable that the granite bathyliths in this region change the invaded limestone into a dark-gray amphibolite, which, together with fragments of the interbanded amphibolites found everywhere in the limestone series, occur scattered throughout the granite mass in the form of included fragments."

The amphibolites are vastly more important areally than the nephelite syenites, and hence the origin of the solutions which left the granite magma and transformed the Grenville limestones to amphibolites is of prime importance. The evidence presented in this article shows a close genetic relation between the amphibolites and the nephelite syenites.

A study of the map published by Adams and Barlow and an intimate knowledge of a portion of the Haliburton area warrant the following statements:

(1) The area embraces some 3456 square miles, a fourth of which is underlain by limestone and amphibolite and the remainder by Laurentian gneiss and amphibolite.

(2) A conservative estimate would show that the amphibolites formed from 30 to 40 per cent of the limestone areas and from 10 to 15 per cent of the gneissic areas.

(3) The contacts of large oval masses of gneiss with the surrounding limestones usually are characterized by a zone of amphibolite mingled with limestone. The average zone is one-quarter to one-half a mile in width and represents a thickness of from one to two thousand feet.

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*Report on Correlation of Pre-Cambrian Rocks, Jour. Geol., vol. xv, p. 204, 1907.

(4) A liberal estimate of the nephelite syenite bodies mapped in the Haliburton region would place their total area below sixty square miles, or less than ten per cent of the area of the amphibolites.

(5) The amphibolites derived from impure lenses in the limestone and those derived from gabbro by dynamic metamorphism are insignificant in amount when compared with the amphibolites derived from the limestone by contact metamorphism.

In view of these facts, it is desirable to know whether the solutions which transformed the limestones to amphibolites were segregated from the granite by juvenile gases, as Smyth has suggested, or whether the interaction of the limestone and the granite caused these solutions to be given off during the formation of the amphibolites.

It is clear from the following analyses that the amphibolites did not result from a simple reaction between definite proportions of the granite magma and limestone. Soda, potash, alumina, and silica are present in the amphibolites in proportions very different from those in the granite.

Table III.

	Analysis of Typical Red Gneiss	Analysis of Amphibolite
SiO_2	76·99 per cent	50·00 per cent
TiO_2	----	0·82
Al_2O_3	12·45	18·84
Fe_2O_3	1·03	2·57
FeO	0·49	5·51
MgO	0·21	4·63
MnO	tr.	tr.
CaO	0·98	10·65
Na_2O	3·46	4·46
K_2O	4·29	1·18
H_2O	0·26	1·00
Cl	none	0·10
S	----	0·03
CO_2	none	0·10
	100·16	99·97

Before discussing this matter, the writer wishes to state a theory concerning the method of emplacement of the Laurentian granite and the origin of lit-par-lit structure in the Haliburton area. It is his purpose to treat the subject in more detail at a later time.

The Grenville series is very thick; how thick, no one wishes to state. Granite pegmatite penetrates this series in every direction. One of the striking facts concerning this area is the predominance of pegmatitic rather than normal granite, showing that the Pre-Cambrian granites which intruded the Grenville series were abundantly supplied with pneumatolytic gases.

It is believed that the presence of these gases made possible the *lit-par-lit* structure of the Haliburton area.* They were capable of penetrating the limestones along planes of weakness, induced probably by static metamorphism,† long before the liquid magma could be intruded. The reaction of the limestones with the gases opened passageways through which liquid magma entered. Gradually, in this way, an immense number of alternating layers of granite magma and limestone were formed. The materials of this gigantic steam pack reacted with each other and produced finally a lit-par-lit structure of granite and amphibolite with a few residual layers of limestone.

The nephelite syenites were developed during the period of intrusion of the granites. Their total mass is far less than one per cent of the total mass of the granites and they are transitional to granite pegmatite through the intermediate stage of red syenite. The nephelite syenite laccoliths occur as small isolated bodies in the limestone or as border facies of the granite.

It has been objected to the syntectic theory of the origin of nephelite syenites that the amount of limestone capable of reacting with the granite magma was entirely insufficient to alter the nature of that magma. The method of emplacement of the granite just described and the large scale production of amphibolites from limestones most effectively removes this objection. If from ten to twenty per cent of the Haliburton area is underlain by amphibolites derived from limestone, then some drastic effects must be looked for in the granite magma which gave rise to the solution producing these amphibolites.

Returning to the question of the origin of the fluids which reacted with the limestone to produce amphibolites, the writer wishes to state very positively that he believes with Smyth that magmatic gases were the effective means of transporting the fluids from the granite into the adjacent rocks. He believes, however, that the soda solutions were given off by the granite magma because lime was capable of replacing soda at high temperatures. The magmatic gases, therefore, were only a means of transportation and were not active in releasing soda solutions from the magma.

If it is believed that the nephelite rocks were segregated independently of the action of limestone, the close association

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*Cf. C. N. Fenner, Jour. Geol., vol. xxii, pp. 594-612, 1914.

†Cf. R. A. Daly, Guide Book, No. 8, Inter. Geol. Cong. Can., Part II, p. 128, 1913.

of the granite pegmatites and the nephelite syenites would lead one to suppose that the same agents, i. e. magmatic gases, segregated two very dissimilar magmas at the same time from the granite. It is difficult to conceive how granite, a magma high in silica, and nephelite syenite, low in silica, could both be transported through the primary magma chamber simultaneously, unless one believes in Rosenbusch's theory that the foyaite and granite kerns are immiscible.

To the writer it appears more reasonable to suppose that soda solutions given off in response to the interaction of the limestone with the granite magma enriched small, confined portions of the granite pegmatite in those elements characteristic of nephelite syenites and so produced the alkaline types.

Such a local desilication of the granite was often observed in the field. Near Bancroft, Ontario, large masses of augite, a foot or more in length, are found near the contact of the granite with the limestone. Wherever these occur, the granite is altered to red syenite and often contains lenses of nephelite syenite. Daly* has shown that lime in the formation of the pyroxene molecule binds to itself 2·5 its own weight of silica. That the granite should be desilicated under these circumstances is not to be wondered at!

At the limestone contact and within the main mass of that rock the granite has produced amphibolite instead of augite from the limestone. The formation of amphibolite binds still more silica than the formation of augite and is, therefore, a more effective means of desilicating the granite.

It has already been stated that the contact of the amphibolite with the limestone is characterized by a scapolitic zone. Scapolite is a mineral high in alumina and often high in soda. It occurs in large masses associated with the corundum syenite of Craigmont, Ontario, and is an essential constituent of most of the nephelite types described from Gooderham and Tory Hill (Part I).

The formation of scapolite is decidedly a case in which soda-rich solutions transported by pneumatolytic gases are given off, due to the interaction of limestone with granite magma. V. M. Goldschmidt† has shown this in his study of the Christiania region. The constant association of this mineral with nephelite in many localities cannot be without significance.

Meionite and nephelite frequently line cavities in the bombs ejected from Monte Somma. Mierisch‡ and Lacroix§ have shown that they were deposited as sublimations from a gaseous

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* R. A. Daly, "Igneous Rocks and their Origin", New York, 1915, p. 431.

† V. M. Goldschmidt, "Die Kontaktmetamorphose im Kristianiagebiet," Kristiania, 1911, pp. 28 and 320.

‡ Bruno Mierisch, Tscherm. Mitth., vol. viii, p. 188, 1888.

§ A. Lacroix, Mus. d'Hist. Nat., Nouv. Arch., (4), vol. ix, pp. 101-2, 1907.

state. R. Brauns* has described the scapolite bombs of the Laacher See district. They, likewise, contain nephelite.

P. D. Quensel† has found vesuvianite, a mineral related to scapolite, as a primary mineral in the canadites of Almunge, Sweden. He concludes, "Hence the possibility must be considered that the vesuvianite is the remnant of a former assimilation process."

V. M. Goldschmidt‡ has recently described the enrichment in soda of a sandstone having numerous calcite lenses. The calcite lenses show an increase in their soda content of 2·58 per cent. The lime was taken into solution and transported to nearby slash veins, where it was redeposited as prehnite, clinozoisite, diopside, and scapolite.

Geological literature has numberless examples of the enrichment of calcareous rocks in soda. Some ascribe this to the susceptibility of limestone to such replacement, but this is but another way of saying that lime and soda easily are interchanged at high temperatures within an igneous magma, or, for that matter, within the laboratory, as those who use the J. Lawrence Smith method for the determination of the alkalies know. If this is true, the emanation of solutions high in soda from a syntectic formed during the intrusion of a granite magma into limestone is to be expected. That such solution did enter the limestones of Haliburton County and transform them to amphibolites has been shown by Adams and Barlow.

Conclusions.—The close association of granite pegmatite with nephelite syenite indicates that they originated from the primary granite magma at approximately the same time. If they were segregated without the aid of foreign material, it would seem that the low percentage of silica in one magma and its presence in excess in the other should have been adjusted by an interaction between the two.

To the writer, it appears more reasonable to suppose that the solutions which gave rise to the nephelite syenites had their origin near the surface, that they were produced by the reaction of limestone with granite magma, and that these solutions enriched certain confined portions of the granite magma in the elements characteristic of nephelite syenites.

If the invading granite magma reacted with the various lenses of limestone between which it was intruded, there would be a possible source of soda solutions. That such solutions were produced is shown by the differential transfer of soda into the amphibolites.

Harvard University, Cambridge, Mass.

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* R. Brauns, Neues Jahrb. Min., Beil. Bd. xxxiv, p. 85, 1912; also xxxix, p. 124, 1914.

† P. D. Quensel, Centralbl. Min., No. 7, p. 205, 1915.

‡ V. M. Goldschmidt., Neues Jahrb. Min., Beil. Bd. xxxix, p. 193, 1914.

ART. XXXI.—*Post-Glacial History of Boston*; by H. W. SHIMER.

CONTENTS.

Introduction.

THE recently completed excavations of the Boston Elevated in the construction of the Boylston Street subway give many new sections down through the mud to the glacial clay. The resulting new exposures of the post-glacial shells through the middle of Back Bay proved to be so interesting that it was decided that a record of them should be kept. The following is a brief summary of this work:

Typical section through the post-Pleistocene sediment.

The following section from the Boylston Street subway excavation at Exeter Street is typical of all the Back Bay sections, and fairly so of all the others from Brookline to City Point.

1.	Fill, in blotting out the Back Bay This fill has taken place mostly since 1868.	16 feet
2.	Gravelly black silt. Few fossils	6
3.	Fine black silt. Many fossils The middle portion is very full of fossils; the uppermost two feet and the lowest foot contain but few. This silt is a dark-gray (when dry) argillaceous sand with a considerable number of mica scales. The compound microscope shows that very minute sand particles make up fully nine-tenths of the mass; there is merely sufficient clay and carbon particles to give consistency and a dark-gray color to the sediment.	5
4.	Sandy, fresh-water peat	5
5.	Blue sandy clay with some peat This is the upper edge of the glacial deposit.	1 foot

The surface of the street here is 16·5 feet above mean low tide, while the bottom of the peat bed is 15·5 feet below mean low tide.

List of species.

The following list includes all post-glacial fossils noted, or listed by previous observers, from Brookline through Back Bay to City Point. Appended to the list are notes upon the peat and the oyster.

1. Plants (unrecognizable fragments)

Foraminifera[*]

2. Polystomella striatopunctata
3. P. sp.
4. Trochammina inflata

Sponges

5. Cliona sulphurea

Bryozoa

6. Membranipora pilosa

Pelecypoda

7. Yoldia limatula
8. Ostrea virginica
9. Pecten gibbus borealis
10. Pecten magellanicus
11. Anomia simplex
12. Mytilus edulis
13. Modiolus modiolus
14. Modiolus demissus var. plicatulus
15. Clidiophora trilineata
16. Arctica islandica
17. Cyclocardia borealis
18. Astarte undata
19. Astarte elliptica
20. Lucina filosa
21. Kellia planulata
22. Laevicardium mortoni
23. Venus mercenaria
24. Gemma gemma
25. Petricola pholadiformis
26. Macoma balthica
27. Tagelus gibbus
28. Ensis directus
29. Angulus tener
30. Mactra solidissima
31. Mulinia lateralis
32. Mya arenaria

Gastropods

33. Acmaea testudinalis
34. A. testudinalis var. alveus
35. Vitrinella shimeri Clapp
36. Turbonilla winkleyi
37. Odostomia trifida
38. Odostomia fusca
39. O. bisuturalis
40. Littorina rudis
41. L. rudis tenebrosa
42. Littorina palliata
43. Littorina littorea[†]
44. Lacuna vincta
45. Crepidula fornicata
46. Crepidula plana
47. Crepidula convexa
48. Polinices heros
49. Polinices triseriata
50. Neverita duplicata
51. Paludestrina minuta
52. Bittium alternatum
53. Triforis nigrocinctus
54. Columbella lunata
55. Cingula carinata
56. Buccinum undatum
57. Nassa trivittata
58. Ilyanassa obsoleta
59. Urosalpinx cinereus
60. Thais lapillus
61. Anachis avara
62. Tornatina canaliculata
63. Melampus lineatus

Crustacea

64. A copepod
65. Balanus balanoides
66. B. crenatus
67. B. porcatus
68. Crab claws

Vertebrata

69. Fish

After an examination of the peat from the subway at Exeter Street, Mr. G. B. Reed of Harvard University writes:

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[*] Identified by J. A. Cushman.

[†] This species was doubtless introduced into the fossil shells by the dredge, since nowhere else upon the American coast is this shell reported earlier than 1855 (Gulf of St. Lawrence). It is apparently a late migrant from Europe.

"I find no plants or remains of plants such as now grow on salt marshes or anywhere below high tide level. But what species have entered into the formation of the peat I can not determine beyond the presence of grasses and sedges, probably both tops and roots, woody roots probably of some Ericaceous plants, and fragments of wood. A large part, however, is made up of much decomposed material now unrecognizable. It has apparently, too, undergone considerable compression as all the stems are flattened."

Ostrea virginica.—This, our only species of oyster, is very rare at Exeter Street, being represented by but three specimens, the largest of which is only 85^{mm} long by 70^{mm} broad. At Charles River this shell is exceedingly abundant including both the long, narrow or so-called "current" form and the short, broad "quiet-water" form. The most usual size of the former is 230^{mm} in length and 55^{mm} in breadth; of the latter the length is 130^{mm} and the breadth 70^{mm}. At Berkeley Street the very large current form is common at a depth of 27 to 31 feet. A valve of one of these, an old individual, with a length of 140^{mm} has a maximum thickness of 50^{mm}. At City Point the specimens are similar in size and abundance to those from Charles River. Miss Bryant figures one from here 265^{mm} by 80^{mm}.

This oyster, as native, is now absent from Massachusetts Bay; during early colonial days it occurred only locally and then, on account of the cold air at such depths as to be exposed only at the low spring tides. A large oyster-bank was situated at the mouth of the Charles River, another at the mouth of the Mystic and probably one on the Noddles Island, now East Boston, flats.

That the large current forms flourished in Back Bay as late as the middle of the seventeenth century is shown by the following quotations:

"The Oisters be great ones in forme of a shoo horne, some be a foote long, these breed on certain bankes that are bare every spring tide. This fish without the shell is so big that it must admit of a devision before you can well get it into your mouth."* . . . . "Towards the southwest in the middle of this Bay" (i. e., Back Bay, at mouth of Charles River) "is a great Oyster-banke" . . . . "The Oyster-bankes" (referring to the same) "doe barre out the bigger ships."

In the first edition (1841) of the "Invertebrata of Massachusetts," Dr. Gould says (p. 357) "old men relate that they were accustomed to go up Mystic River and Charles River, and gather oysters of great size, before it was the custom to

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*New England's Prospect, etc."; William Wood, London, 1634. Prince Society Edition, 1865, pp. 39-44.

bring them from New York. And even now individuals of enormous size are occasionally brought from both these places, and probably might be found by special search, at any time." The cause of this great numerical reduction since colonial days is said to be a very severe cold spell about 1780 in which the sea bottom was covered with ice, thus preventing the oysters from getting air.

Another factor which aided in the destruction of some of these species, especially the oyster, from the Back Bay region was the gradual obliteration of Boston as an island by the formation of a neck uniting it with the mainland to the south. Even during late colonial days heavy seas washed over this neck into the Back Bay. Oysters need a clean substratum, such as gravel, or other shells, to which the young, the spat, may attach themselves, otherwise they will perish; and the opening across Boston neck would give the tidal currents extra strength with which to cleanse this partially enclosed region from the river muds; but that this was never so exposed to the action of waves as at City Point is shown by the occurrence of the surf-clam (Mactra solidissima) at the latter place only.

Many plantings of the oyster spat in its old home in the Charles River during recent days have resulted merely in the death of the spat.

Conclusions.

The deposition of the blue clay took place probably in a body of fresh water, since no remains of animal life are apparent in it. The clay itself, derived from a near-by melting glacier, is the so-called glacial flour,—the material ground from the rocky floor by the stones held firmly in the advancing ice. A few unidentified pieces of wood were noted in this clay. After the glacier had melted away from this region, the area was subjected to erosion by running water as evidenced by the gullies in the surface of the clay as well as in the sand plains (fossil deltas deposited by glacial streams). At the Longwood Bridge, Brookline, the sand-plain was eroded to a depth of 37 feet. During and subsequent to this erosive period, or at least the latter part of it, fresh-water peat was broadly developed. The land was at this time sinking with reference to sea-level, and continued its downward motion until the sea invaded the area under discussion. The evidence that the peat in Back Bay furnishes in regard to this downward movement is as follows:—

The bottom of the peat at Fairfield Street is 23 feet below low tide, at Exeter Street 15·5 feet, at Church Street 33 feet, and at Charles Street it is 27 feet.

With a height of tide of 10 feet, as it was in the Charles River before the construction of the tide-water dam, it would mean a submergence of this region of at least 33 plus 10, or 43 feet; and if the peat was formed far above sea-level it would mean a so much greater submergence.

Following the submergence occurred the deposition of the black silt, with which were enclosed shells and other records of the life then living in these waters. This record is of primary interest because of the evidence it furnishes as to a warmer period between the presence of glaciers here and the present. That the climate of Boston has become slightly colder since the time of the maximum development of this fauna is shown in the change in the present distribution, especially of the mollusks, for all are still living. Of the sixty some species noted from the localities given, about half no longer occur north of Cape Cod, or only rarely in sheltered areas, but find their perfect environment farther south. These forms belong to the Virginian fauna, which is typically developed from Cape Cod to Cape Hatteras, though some of the species also thrive northwards in a few protected places. Ganong* mentions nine such areas, including the Gulf of St. Lawrence, Oak Bay, New Brunswick, Casco Bay, Maine, and Massachusetts Bay. Between the retreat of the ice from this coast and the present time a period must have occurred during which the waters were as warm as those from Cape Cod to Cape Hatteras, and during which this Virginian fauna migrated northward. This was followed by a gradual refrigeration of the waters sufficient to prevent the breeding of many of the species except within a few areas protected enough to raise the temperature of the air and water sufficiently during the summer, or breeding season, for the development of the young. The following are some of the principal post-glacial fossils of Boston occurring thus rarely or not at all to the north of Cape Cod,—*Ostrea virginica*, *Venus mercenaria*, *Pecten gibbus borealis*, *Laevicardium mortoni*, *Triforis nigrocinctus*, *Mulinia lateralis*, and *Vitrinella*. That this refrigeration continued during early colonial days is shown by the later disappearance from the vicinity of Boston of such species as the then abundant oyster, and the great reduction of many others both in number and in size.

Most sections through the black silt in the Back Bay area show a more fossiliferous lower portion and an upper portion with comparatively few fossils. This difference may be correlated with the partial closure of Back Bay by the tidal building of Boston Neck; the consequent reduction in tidal scour would then cause a more rapid accumulation of sediment within the Bay.

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* W. F. Ganong, Trans. Roy. Soc. Can., vol. viii, Sec. 4, pp. 167–185, 1890.

A small portion just beneath the "fill" may be due to the presence of dam walls built in the early part of the 19th century. In 1814 a corporation,—"The Boston and Roxbury Mill Corporation," led by Uriah Coting, obtained a charter from the General Court empowering them to build a dam from the end of Beacon Street (at Charles St.) to Sewell's Point in the uplands of Brookline, with a cross dam to Gravelly Point in Roxbury; also to make a roadway of each dam and to levy tolls for its use. It could confine tide water within this area and run mills by the water power thus created. At this time there was nothing but water and salt marsh from the foot of the Common to the uplands of Brookline. The mill dam was finished in 1821. But the tidal power, rather insufficient at the beginning for the running of the mills, was soon encroached upon, first, by the owners of bordering property filling in their land, thus restricting the area of the dam; and especially, secondly by the building of the Boston and Providence and the Boston and Worcester Railroad across the water basin (incorporated in 1831). With this restriction of the tide and the increase in population this basin soon became a public nuisance, and in 1852 a commission of the state legislature recommended that the property be abandoned for mill dam purposes and be filled in for building purposes. This was finally done, giving as a result the topmost 15 to 20 feet in the above Back Bay sections.

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SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *The Improvement of High Boiling Petroleum Oils.*—For a long time it has been known that a sufficient heating of high boiling oils, a process called cracking, will cause them to break down into lower boiling oils or even gases with the deposition of carbon. A difficulty in the practical application of this cracking process lies in the fact that in breaking down the high boiling hydrocarbons into simpler ones there is not enough hydrogen to saturate the newly formed bodies, in spite of the deposition of carbon, so that the products contain large amounts of unsaturated hydrocarbons, which give them undesirable qualities. Such products can, of course, be refined somewhat with sulphuric acid, but there must be too much acid used and too much oil lost to permit in practice a thorough treatment with the acid. A. M. McAfee has applied Friedel and Craft's reaction, that is, treatment with anhydrous aluminium chloride during the distillation, for the purpose of converting high boiling into low boiling oils, and he has found that with proper control of the vapors leaving the distilling system and entering the final condenser, and with sufficient time given the aluminium chloride, there is a complete transformation, and no matter how unsaturated the high boiling hydrocarbons may be, the low boiling oils produced from them are sweet smelling, water white and saturated. The reaction gives little gas, and only about the right amount of carbon is deposited to allow for the production of saturated products. In carrying out the process in practice, the crude oil is first heated in the still to render it anhydrous, and also distil off any gasoline and kerosene that it may contain originally. In many of our crude oils, especially some of those from Texas, California, and Mexico, there is practically no gasoline and very little kerosene present. Anhydrous aluminium chloride is then added to the extent, apparently, of 5 to 7½ per cent, the mixture is stirred and heated to boiling, usually at a temperature of about 500° F. The still is provided with large, air cooled, trap condensers which cause the condensation and the return to the boiler of the higher boiling products and of the aluminium chloride and its compounds. When the vapors are allowed to pass into the final condenser at a temperature of about 300° F. the product is gasoline alone, which is ready for market when washed with an alkaline solution. The operation is carried on until the least valuable, so-called gas oil, portion of the oil has been converted into the low boiling distillate, then the operation is stopped, and the more valuable higher boiling part is drawn off from the coky residue containing the aluminium chloride, in order that it may be worked up for lubricating oil and paraffine products. The latter products are

much improved by the aluminium chloride treatment, as they are thus saturated, and the resinous and asphaltic constituents are eliminated. The aluminium chloride is recovered for further use, best by distillation in an atmosphere of chlorine.—*Jour. Indust. and Eng. Chem.*, vii, 737. H. L. W.

2. *Arsenious Oxide as an Alkalimetric Standard.*—Alan W. C. Menzies and F. N. McCarthy have found that arsenious oxide may be employed with accuracy, and without too complicated manipulation, as a primary standard in alkalimetry. A good quality of the oxide is purified by subliming once in a 6 × 1 inch test tube which has been drawn down to one-fourth its bore at a point about 2 inches from the closed end. The product is dried by heating and bottled hot. To prepare 500^{cc} of $\frac{1}{10}$ N. solution a quantity of about 2·47 g. is weighed accurately in a 75^{cc} conical flask. This is then treated with 5^{cc} of pure, concentrated nitric acid followed by 5^{cc} of water. Solution and oxidation are effected by careful heating with a suitable trap attached to the mouth of the flask to avoid loss by spattering, and 5^{cc} more of concentrated nitric acid are added. The nitric acid is now removed by evaporation, best by the aid of a jet of cotton-filtered, ammonia-free air. The heating can go as high as 230° C., but it is necessary to take up the residue in water and evaporate to dryness twice in order to remove all of the nitric acid. It is then only necessary to dilute to the required weight or volume of solution. To a measured quantity of about 30 or 40^{cc} of the solution are added phenol-phthalein as indicator and 3 or 4^{cc} of saturated barium chloride solution. The alkali is then run in until the amorphous white precipitate, formed locally, is rather slow in re-dissolving, then the glass surface beneath the liquid is scratched until the lustrous, silky, crystalline precipitate of $BaHAsO_4$ begins to form, when the titration is completed in the usual way. Carbonate-free sodium hydroxide, containing barium hydroxide, may be used as the alkaline solution. The authors compared this method of standardization with several other accurate methods and obtained practically identical results in all cases.—*Jour. Amer. Chem. Soc.*, xxxvii, 2021. H. L. W.

3. *A New Method for the Qualitative Separation and Detection of Arsenic, Antimony and Tin.*—F. L. Hahn has proposed the following method, which he considers preferable in the hands of students to the methods usually employed. Starting with the mixture of the higher sulphides of the three elements mixed with much sulphur, this is extracted in the cold with a 5 per cent solution of Na_2S. The sulphides go into solution very easily, while the sulphur remains behind. To the filtered liquid 10 per cent NaOH is added to the extent of about double the Na_2S solution used. Then an excess of hydrogen peroxide is added and the mixture is boiled. In the presence of antimony a crystalline precipitate of $Na_2H_2Sb_2O_7$ soon begins to separate, and the precipitation of the antimony is made complete by cooling and adding about $\frac{1}{4}$ the volume of alcohol. The precipitate is then

filtered off, the alcohol is boiled off, ammonium nitrate, best in the solid state, is added. This precipitates stannic hydroxide, and after the ammonia has been boiled off the precipitation is complete. From the filtered liquid NH_4MgAsO_4 may now be precipitated as usual. It is stated that in this manner 1 mg. of arsenic, 1 mg. of antimony, and 2 mg. of tin can be detected with certainty in 1 g. of copper or lead.—*Zeitschr. anorgan. u. allgem. Chem.*, xcii, 168. H. L. W.

4. *An Alleged Allotropic Form of Lead.*—Hans Heller has found that when thin strips of lead are placed for 3 days or more in a solution containing 1000 cc. of water, 400 g. of lead acetate, and 100 cc. of nitric acid of 1·16 s. g., the metal loses completely its original solidity and ductility and falls into small gray to grayish-black particles which can be rubbed to a powder between the fingers. It was found that the presence of a lead salt in solution was necessary to produce this change, and the conclusion was reached that the transformation is analogous to the well-known change of white tin into gray tin. It was found impossible, however, to change ordinary lead into the gray product by inoculation with the latter, so that it is evident that the analogy to tin is not complete. Although it is stated that the change is not a chemical one but an actual transformation of lead into a new modification, this does not seem entirely plausible, and it appears that a further study of the matter is desirable.—*Zeitschr. physikal. Chem.*, lxxxix, 761. H. L. W.

5. *Reflection of Gas Molecules.*—Certain phenomena associated with the flow of gases have led to the assumptions that, on collision with a solid wall, the gas molecules are reflected at angles which are independent of the angle of incidence, and that the number of molecules reflected in any given direction is proportional to the cosine of the angle which this direction makes with the normal to the reflecting surface. An attempt to verify these hypotheses by direct experiment has been recently made by R. W. Wood.

The first experiments related primarily to the production of a one-dimensional flow of gas. The apparatus consisted essentially of a vertical glass tube with a small bulb at the lower end and a constriction just above the bulb. A short segment of the upper portion of the tube was bent through an angle of about 130° so as to form a convenient reservoir. In short, the apparatus had the general appearance of the ordinary form of cryophorus. A globule of mercury was first introduced into the bulb and then the apparatus was exhausted to as high a degree as possible. During the process of evacuation the tube was heated with a Bunsen flame to drive out the occluded gases from the glass walls. After the apparatus had cooled sufficiently the bulb alone was heated, thus causing the mercury to condense in the upper portion of the tube. The pumping was continued until all of the mercury had been driven out of the bulb and the lateral reservoir had been sealed by fusion. By simple manipulation the mercury was collected as a droplet in this reservoir. Finally, the bulb and all of the straight, vertical segment of the tube were immersed in liquid air. At the expiration of twelve hours a faint circular deposit of mercury, having the same diameter as the lower constriction in the tube, was observed at the bottom of the bulb. By winding a heating-coil around the lateral reservoir and causing the mercury to distil at a temperature appreciably above that of the room, the deposit in the bulb was established in a minute or two. In the original paper is given a clear photograph of the mercury which had condensed on a glass plate placed in the bulb obliquely with respect to the long axis of the tube.

The phenomenon is explained very clearly in the following sentences. "The mercury vapour enters the upper portion of the tube, and all of the molecules which are moving sideways are condensed on the wall, the deposit being very heavy at the top of the tube, and gradually thinning away to nothing a few centimetres below the surface of the liquid air. Below this point the molecules are moving all in the same direction, like bullets from a machine gun, and no further deposit is found until the constricted portion of the tube is reached. Here the molecular stream strikes the sloping walls of the constriction, and a heavy deposit of the metal occurs. Passing through the small opening, the gas traverses the exhausted bulb in the form of a jet which shows no tendency to spread out laterally, and deposits on the wall in the form of a small circular patch with very sharply defined edges."

In order to study the reflection of the beam of molecules a large drop of glass, at the extremity of a thin glass stem, was ground down and polished plane at an angle of about 45° with the axis of the stem. The reflecting surface was mounted concentrically with the evacuated bulb by sealing the end of the stem to the inside of the lower, or drawn-out, portion of the bulb. The insulating stem and the surrounding vacuum enabled the reflecting surface to maintain its initial temperature, which was well above the point of condensation of mercury vapor, for an interval of time much longer than was necessary for the completion of the observations. Under these conditions, the deposit began to appear in about three minutes after the heating-current had been started, and in ten minutes it had become entirely opaque to ordinary light. The photograph shows that the deposit covers the upper oblique half of the bulb *with the exception of a narrow circular zone just above the plane of the reflecting surface.* "The results appear to show that the cosine law is approximately followed, for the density is greatest on the line of the normal, falling off gradually as the angle increases. At angles greater than about 80 degrees there appears to be no reflexion, at least in the case of the two surfaces which I have examined." The second surface referred to was a sheet of mica freshly split and mounted on a glass plate. The occurrence of the blank zone was also found to be independent of the size of the bulb and of the angle between the reflecting surface and the axis of the incident beam of molecules. As yet no satisfactory explanation of the cause of the superior limit of the angles of reflection has been published.—*Phil. Mag.*, xxx, p. 300, August, 1915. H. S. U.

6. *The Stark Effect for Solids.*—The question as to whether excitation by canal-ray bombardment is a necessary condition for the electric resolution of spectral lines is suggested by the fact that in the single case where a different mode of excitation was employed, the Stark effect could not be detected. During the past year this problem has been attacked by C. E. Mendenhall and R. W. Wood, and negative results were invariably obtained. This fact is of no little importance at the present time and hence a brief account of the experimental conditions may be of general interest.

Most of the data were obtained photographically with grating spectrographs, and the electric fields were applied by means of a motor-driven Wimshurst machine. In order to have the spectral lines as narrow as possible the solids studied were usually maintained at the temperature of liquid air. The strong, sharp fluorescent line at λ 5736, which was radiated by a certain specimen of Weardale fluorite, was the first to be examined. A gradient of about 50,000 volts per cm. produced no sensible change in the line which was excited (at room temperature) by the light from a heavy spark between magnesium electrodes. Also this field did not alter the amount of polarization of the light which was emitted at right angles to the lines of force. An attempt to detect the longitudinal Zeeman effect, at liquid-air temperature and with a field of 22,000 gauss, met with no success. Negative results were likewise obtained when the line was examined for selective absorption of its own wave-length, both with and without fluorescent excitation.

The next lines studied were the brilliant red fluorescent pair of the ruby (λλ 6932 and 6946), which are stimulated by a wide range of visible and ultra-violet radiations, but most strongly by the yellow-green. A field of 45,000 volts per cm. did not produce the slightest change in these lines. In this case there is a sharp absorption doublet of the same wave-lengths, but this too was quite uninfluenced by the electric field. When the temperature of the ruby was changed from 23° C. to −180° C. the lines became much sharper and each one shifted toward the violet by 12 Å. A number of interesting phenomena were presented by the eighteen lines of the fluorescent spectrum when examined in magnetic fields, but lack of space and diagrams will necessitate reference to the original paper. With regard to the resonance radiation of the ruby the authors make the following remarks. "Careful tests, using sunlight dispersed by a monochromatic illuminator to excite with, showed that the strong red emission lines are excited by light of their own wave-length. This, or a similar effect in the case of a solid or liquid, has not been before observed, so far as we are aware, and it is a difficult thing to catch, since the fluorescence is much fainter than when a broad spectral region is used to excite. However, there was no question that as the exciting light was changed from the yellow through the red, the fluorescence first gradually disappeared and then suddenly appeared again as the wave-length of the line itself was passed. This is indeed just what would be expected with a line showing selective absorption and therefore due to a normal mode of vibration." "Comparing the fluorite and ruby lines, then, we have one showing no corresponding absorption, no synchronous resonance, no Zeeman and no Stark effects; this line *may* not be a normal mode; the other shows absorption, resonance radiation, and Zeeman effect, but no Stark effect, and apparently *is* a normal mode."

The "inverse" Stark effect was searched for in vain in the case of the fine absorption lines of monazite, praseodymium sulphate, neodymium sulphate, neodymium nitrate, and uranyl nitrate. Visual observations alone were made, the crystals being maintained at liquid-air temperature and subjected to gradients from 45,000 to 60,000 volts per cm.—*Phil. Mag.*, xxx, p. 316, August, 1915. H. S. U.

OBITUARY.

PROFESSOR FREDERICK WARD PUTNAM, the distinguished anthropologist and naturalist, honorary curator of the Peabody Museum at Harvard University, died on August 14 in his seventy-seventh year. He was a man of untiring energy, effectively exerted not only in ethnological research, but also in museum development and in various lines of administrative work.

DR. JOHN HOWARD VAN AMRINGE, professor of mathematics in Columbia University from 1865 to 1910, and for many years dean of the faculty, died on September 10 at the age of seventy-nine years. During half a century of service, his ability and wisdom as a teacher and dean, and his charming personality, won for him an enviable place in the esteem and affection of thousands of students.

DR. KARL EUGEN GUTHE, professor of physics in the University of Michigan and dean of the Graduate School, died on September 11 at the age of forty-nine years.

DR. PAUL EHRLICH, the distinguished German pathologist, director of the Institute for Experimental Therapeutics at Frankfurt, died on August 20 at the age of sixty-one years.

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[FOURTH SERIES.]

Art. XXXII.—*Experimental Studies and Observations on Ice Structure*; by O. D. von Engeln.

Introductory.—A detailed account of these experiments has been published under the joint authorship of the late R. S. Tarr and the present writer in the *Zeitschrift für Gletscherkunde* (1915, vol. ix, pp. 81–139). In view of the restrictions imposed by the European situation, the fact that the Zeitschrift reaches only glacialists and that new points have come up since the writing of the longer article, it is deemed worth while to summarize the chief results obtained in an American periodical. Those specially interested in the subject are, however, referred to the fuller statement which contains the records, data, and methods followed in individual experiments, references to earlier literature, and acknowledgment to those who gave assistance in various ways.

The initiative in developing the work and some of the tentative conclusions are to be credited to the late Prof. R. S. Tarr. The experiments furthermore comprise the continuation of the investigations begun by Professor Tarr in the winter of 1910–11. The earlier results were published under the title "The Properties of Ice—Experimental Studies," by R. S. Tarr and J. L. Rich.* The experiments herein described were performed in the winter of 1911–12, when better facilities and apparatus were available.

Record of the Experiments.—The experiments were planned primarily to secure data bearing on the structure and flow of glacial ice. In the main they consisted of compression tests (*a*) on cubes of ice unsupported at the sides and (*b*) on cylinders of ice enclosed in metal cases of varying degrees of resistance up to complete rigidity under the pressures applied. The

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* Zeitschrift für Gletscherkunde, vi, pp. 225–249, 1912.

Am. Jour. Sci.—Fourth Series, Vol. XL, No. 239.—November, 1915.
30

tests were made with screw presses designed and calibrated by Professors Kimball and Wells of the Sibley College of Mechanical Engineering, Cornell University. (See fig. 1.) Both pond and glacier ice were used, in cubes ½, 1, and 2 inches square and variously oriented with regard to the component crystal structure of the ice. It was found that the crushing strength of pond ice with pressure applied in the direction of the principal axes of the component crystals (all similarly oriented) is about 1000 lbs. per square inch. With pressure at right angles to the principal axes the crushing strength was approximately 350 lbs. to the square inch, while that of

Fig. 1.

Fig. 1. Interior of Outdoor Laboratory. Shows large press with ice core projecting to right from lateral orifice of iron cylinder. Also shows small press (on table in background) with one of the small cubes between its plates.

glacier ice with variously oriented crystal grains was at some figure intermediate between 350 and 1000 lbs., and tended to the higher rather than the lower figure. These data were obtained with air temperatures between 18°F. and 20°F., but variations between 10°F. and 25°F. do not seem to have a notable effect on the strength of the ice. Great care was exercised to have the pressure faces as nearly parallel planes as possible and pressures were applied very slowly. In a number of instances increases of the load were made only after a number of hours interval; in several cases a single test occupied from 16 to 20 hours time.

The values of the crushing strength of ice here stated are notably higher than those obtained and approvingly cited by H. T. Barnes in recent papers.* The average values he quotes are 370 lbs. per sq. inch, pressure parallel to the principal axes, 356 lbs. pressure normal to the axes. The discrepancy in the first case is probably due to the following factors: (*a*) The ice used by Barnes was river ice and because of current action may not have had uniformly oriented crystals, especially as large size blocks, 7 inches square, were used in the tests; (*b*) the tests were made at air temperatures only a few degrees below freezing point and in some cases above that point; (*c*) the pressures were applied with comparative rapidity. The authors of the second paper cited use an average figure of 400 lbs. to the square inch as the crushing strength of ice in calculating the linear thrust of ice sheets against dams. As such thrust would be exerted at right angles to the principal axes the value of the crushing strength used is probably amply high for engineering practice.

It was repeatedly noted when working with cubes under pressure approaching the crushing point that cracking occurred when the pressure was relieved and that if the pressure release was at all rapid the ice actually broke apart. This indicates that ice yields elastically to pressures slowly and carefully applied and that the elastic rebound is not sufficiently rapid to enable the ice to withstand quick release of pressure, hence the differential stresses set up by the rapid release suffice to rupture the mass. On account of this elasticity it appears that there can not be any permanent deformation of ice until a certain minimum stress has been applied and the experiments showed that the yield-point is near the crushing strength of the ice.

If, however, pressures just below the crushing strength of the ice are applied and continued for a sufficiently long time

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* Barnes, H. T.: The Crushing Strength of Ice, Trans. Roy. Soc. Canada, Third Series, vol. viii, pp. 19–22, 1914. Barnes, H. T., Hayward, J. W., and McLeod, N.: The Expansive Force of Ice, ibid., pp. 22–49.

the ice will yield by flow without breaking. In this way the ice can be permanently deformed. Moreover, once such flow is initiated it continues for some time despite a progressive diminution of pressure. This experiment was repeated a number of times using cubes of ice ½-inch square. Thus on January 16, 1912, air temperature 8°F., such a cube of pond ice was inserted in the press and a pressure of 260 lbs. applied in the direction of the principal axes. Nineteen hours later the cube had flattened to one and one-half its original area and pressure had fallen off to 230 lbs. In the cases of four other similar cubes the pressures fell off to 223, 223, 230, 226 lbs., a strikingly narrow range. The cubes were reduced to one half or one fourth their original thickness. Under the petrographic microscope it was apparent that the original crystal structure had been deformed, but the flattened ice was apparently as strong (coherent) as the original pieces, although the edges exhibited curved fractures parallel to the pressure direction. Glacier ice flowed and flattened similarly but only 185 lbs. of pressure could be initially applied to ½-inch cubes of such ice and at the end of flattening the pressure was about 159 lbs. As the air temperatures during these experiments were 20°F. and lower, it would seem that the yield and flow is not due to pressure melting and regelation unless this be conceived of as occurring between the particles of the crystal structure of the ice.

Various kinds and forms of ice, also snow, were compressed in metal cylinders to determine (a) whether any change in crystalline structure could be brought about by pressure only, and if so of what nature, and (b) whether actual continuous flow of ice could be induced by pressure at temperatures sufficiently low to render pressure melting and regelation inoperative. Lead cylinders, open at both ends, were first used but these yielded at pressures of 720 lbs. per square inch and the ice within crushed as the cylinder sides bulged outward. In later trials copper cylinders 4 inches in diameter, 12 inches high with walls 1/16 inch thick were used.

Into such a copper cylinder a rough-hewn plug of pond ice was inserted with component crystals parallel to the length of the cylinder, and water frozen in the space between the rough-hewn core and the metal walls, making a solid ice filling. To the ends of this cylinder a pressure of 500 lbs. per square inch was applied, part of the load being borne by the metal edges of the casing. The air temperature when the pressure was applied was 17°F. and several hours later when the pressure was increased to 720 lbs. per square inch it had fallen to 15°F. On the next day at 9 A. M. the air temperature was 6°F. and no bulging of the cylinder or falling off in pressure was apparent. Accord-

Fig. 2.

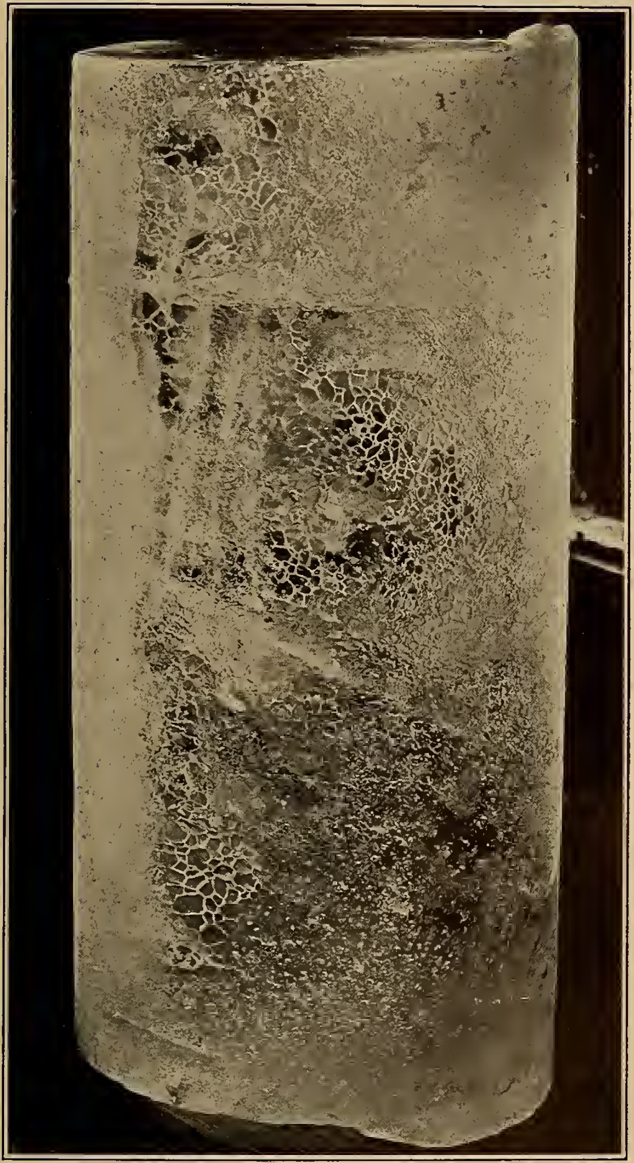

Fig. 2. Ice compressed for 94 hours at air temperatures ranging between −4°F. and 20°F., under pressures up to 1400 lbs. per square inch. Photographed immediately after removal from copper cylinder. Note that there is no distortion from the cylindrical shape. Note also the etched outlines of the outcropping ends of the crystals.

ingly the pressure was raised to 750 lbs. per square inch. The following night the temperature fell to a minimum of —4°F., and no change was apparent in the cylinder or pressure the next day. At four o'clock in the afternoon, air temperature 13°F., the pressure was raised to 1400 lbs. per square inch, the upper limit of the calibrated scale of the press. At this pressure the cylinder was allowed to stand for 36 more hours, the air temperature meanwhile rising to 20°F. Then the cylinder was removed from the press. It had been under varying pressures for some 94 hours at air temperatures ranging between —4°F. and 20°F. On gently heating the metal cylinder it was found possible to slip the ice core out complete, indicating that there had been no bulging or distortion of the metal. (See fig. 2.)

The compressed ice was found to be of crystal clearness and homogeneous, showing no line of separation to mark the juncture of the rough-hewn prism of pond ice and the water frozen around it. The most striking result, however, was the fact that *the ice mass had been completely recrystallized.* The original pond ice core was inserted with principal axes parallel to the pressure direction, the new crystals extended across the cylinder with their principal (and longer) axes at right angles to the pressure direction. On slow melting and evaporation in the laboratory the individual crystals 1/16 to 3/16 inches in diameter and averaging 3/4 inch to 1 inch in length were outlined by grooves along their contact planes. A further singular phenomenon was the extension of the crystals straight across the cylinder instead of radially inwards as might have been expected by analogy to the structure of cakes of can-frozen artificial ice. The boundaries of the crystals were irregularly polygonal, an occasional one nearly hexagonal, much like glacier grains in cross section but differing from these in that the crystals of the cylinder were greatly elongated. (See figs. 3 and 4.) Under crossed nicols a section cut across one of the crystals exhibited parallel extinction, indicating that it comprised a single, uniform individual. Others showed wavy extinction in section, suggesting distortion, as is also true of glacier grains. In no case, however, were any traces of brecciation apparent. The elongated form and wedge-shaped terminations in the artificial crystals may have owed their difference from the glacier grains to the fact that the conditions of our experiment permitted of no movement in the ice mass involved.

In a later experiment this last deduction was in a sense verified. An annealed, softer, copper cylinder was filled with ice fragments of pond ice, glacier ice and snow in layers, and made solid by filling up the spaces with water and freezing. Pres-

FIG. 3.

FIG. 3. Same ice cylinder as shown in fig. 2 after reduction in size by slow melting and evaporation (mostly latter) in outdoor laboratory. Note outlines of crystals as shown by etching out of crystal boundaries into distinct grooves. Natural size approximately 8 in. high by 4 in. wide, original cylinder 12 in. by 5 in.

FIG. 4.

FIG. 4. End view of ice cylinder shown in fig. 3 and photographed at the same time. Shows roughly parallel orientation of crystals, their relative lengths and wedge-shaped terminations.

sure was applied to the top of this composite filling by means of a solid iron plunger turned to a diameter that would just permit its easy insertion into the open end of the copper cylinder. This insured all the load being borne by the ice itself. (See fig. 5.) Pressures varying from 500 to 900 lbs. per square inch were applied, over a period of five days. The cylinder bulged after the first few hours. As no notable change in the ice was apparent on removal from the cylinder after this treatment except the absence of fracturing and apparent flow indicated by the transparency and coherence of the mass, the same ice core was utilized again. This time an unannealed harder cylinder was probably used (our notes fail to state) and a solid ice mass assured by filling with water and freezing. Again using the iron plunger, pressures up to 1000 lbs. per square inch were applied and allowed to remain on over night. Next day the load had fallen off to 800 lbs. per square inch and the cylinder was very slightly deformed. The air temperatures during the time of the experiment ranged from 16° to 19° F.

Fig. 5.

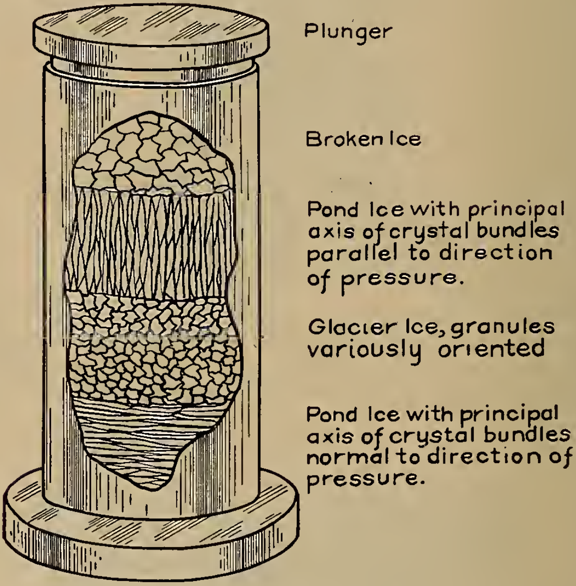

Fig. 5. **Diagram illustrating contents of annealed copper cylinder, using fitted iron plunger.**

On removing the ice from this second cylinder it was found to be completely recrystallized. Ends of individual crystals had diameters 1/8 to 3/8 inches, some were smaller. The originally glacier ice was coarsest, the crushed top ice finest, but all parts showed the same granular structure, but not elongated crystals, and the grains were also variously oriented crystallographically. The appearance of this cylinder is shown in fig. 6.

As the ice of this cylinder had a complicated history the experiment was repeated with an annealed cylinder filled with cracked pond ice and snow only, no water frozen in. This was compacted with pressures up to 1400 lbs. per square inch with much swelling of the cylinder. Then the plunger was removed and more filling of snow and cracked ice put in. This experiment was carried on for about 5 full days, air temperatures meanwhile ranging between 5° and 27° F. On removal from the cylinder the cracked ice layers were found to be clear and glassy, the snow layers glassy but clouded with innumerable air bubbles; the whole was a homogeneous ice mass. On melting down the characteristic, granular structure, obtained in previous experiments, was found to have developed in this also in all parts, but the grains were larger in the layers of cracked ice. Under crossed nicols extinction was found to be uniform within a given grain boundary. Similar results were obtained on compressing snow alone.

It seems from these experiments that a granular ice can be developed from snow by pressure with accompanying movement at air temperatures eliminating the possibility of pressure melting and regelation. The pressures required to bring about flow and change of structure are also interesting, in that they correlate so nearly with the yield point pressures obtained in the unsupported cube experiments. It is to be remembered, however, that the pressure figures for most of the metal cylinder experiments are by no means exact, inasmuch as the area to which pressure was applied must have been constantly changing as the cylinder swelled, and can hardly have been transmitted uniformly per unit of area throughout the mass during the progress of the experiment.

In the second type of the compression experiments with metal cylinders it was planned to test the possibility of free and continuous flow of ice at temperatures sufficiently low to eliminate the development of pressure melting and regelation. A heavy iron cylinder bored out to 2 5/16 inches diameter, with a lateral orifice 3/4 inch in diameter, near the solid base was used. A solid steel plunger was turned to fit very accurately into the larger opening of the cylinder. It was proposed to force ice placed in the cylinder through the lateral orifice by applying pressure by means of the steel plunger. The arrangement of the experiment is clearly shown in fig. 1.

On March 5th at an air temperature of 22° F. the cylinder

FIG. 6.

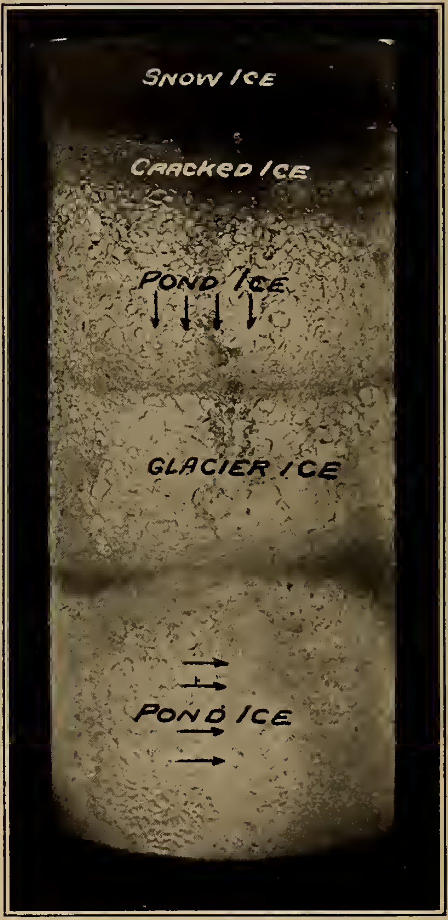

FIG. 6. Ice cylinder of fig. 5 after second compression. Position and boundaries of different kinds of ice used in filling as marked. Note that lines of juncture of different kinds of ice are nearly obliterated and that the crystal ends bridge them. Outline of the old top of ice from first compression shown faintly under the snow ice, indicating transparency of latter. Granules shown to be largest in glacial ice.

was filled with ice fragments and a pressure of approximately 3400 lbs. per square inch applied by 5 P. M. of that day. During the night the air temperature decreased to 4°F. Before 10:30 A. M. of the next day, when the air temperature was 14°F. 3 inches in length of solid ice core had been forced out of the lateral orifice at the base, and the pressure had fallen off to 3000 lbs. per square inch. (See fig. 7.) The projecting ice rod curved downwards, its end being one-half inch below the level of the orifice. By 2:30 P. M. 4 1/2 inches were projected. By 4:30 P. M. another inch had been squeezed out, the pressure had fallen off slightly and the air temperature had risen to 29°F., at approximately which point it stayed until 10 A. M. next morning when 14 inches of ice rod had been

Fig. 7.

Fig. 7. Flow of ice under compression. Photographed at 12.15 p. m. on March 6, 1912. Air temperatures ranged between 22°F. when pressure first applied, to 4°F. during night and 14°F. in morning when 3 inches of ice had been protruded. In this figure approximately 4 inches of the "squeezed out" ice rod are shown. Streaks are due to iron substance from orifice and indicate the movement outward. Note downward bend of rod. Parallel rings near end are original, their cause not understood.

pushed forth. Two hours later the air temperature rose to the freezing point and the pressure had fallen off to 2000 lbs. per square inch. The air temperature continued to rise slowly, and by 2 P. M. water from pressure melting began to ooze out at the top of the cylinder between its bore and the steel plunger but no water came out of the lateral orifice with the ice rod, which had meanwhile increased another two inches in length, making 16 inches in all ; the load at the end being 1100 lbs. per square inch. That the water oozing out at the top was from pressure melting was indicated by the fact that it refroze in feathery crystals on the outside of the cylinder.

Microscopic sections cut on March 6th from the part of the rod protruded at the lowest temperatures on examination proved the ice to be perfectly clear, glassy and compact. Under crossed nicols individual particles proved to be differently oriented but exhibited parallel extinction within a given boundary. The outer circumference was finer grained than at the core, shear lines and breccia bands could be identified but there were some apparently real crystal boundaries. "Undoubted breccia bands and undoubted boundaries of breaking, but looks for all the world like a medium-grained granite rock, with a very few apparent crystal edges but not usually. The fact that this is clear compact ice shows beautiful flow." (Tarr's laboratory notes.)

The downward bend of the rod may have been due to more rapid emergence at the top than the bottom of the orifice. If so, the differential movement may account at least in part for the breaking and shearing. However, the rod may have bent of its own weight or because of internal stresses. Clay squeezed through like orifices in clay-working machinery bends down similarly because of irregularities in the material.

Interpretation and Application of the Experiments.—Ice crystallizes in the hexagonal system. The habitus of the crystals and their orientation vary according to their origin. In the lake ice the crystals occur in bundles of prisms with the basal planes of the mass parallel to the refrigerating surface. In glacier ice more or less nodular grains, each a crystal unit, form an interlocking aggregate with the principal axes of the individuals variously oriented, although some observers claim that there is a measurable tendency for the grains in the basal layers of glaciers to be disposed with their principal axes parallel to the direction of gravity. Water freezing in crevasses in glaciers has been noted to develop columnar ice crystals with principal axes extending at right angles from the opposing walls of the fissure. In artificial ice frozen in cans submerged in ammonia-cooled brine the crystals have their principal axes extending radially from the outer surface to the center of the cake. Emden* has clearly shown that ice grains as large as hazel nuts may be grown from snow slush with originally small ice nuclei, kept in sealed vessels for several weeks at a constant temperature of 0°C. In this case growth proceeds from the center outward, the accretion and orientation of each crystal being determined by the orientation of the original nucleus. Accordingly the orientation of the grains in the mass is irregular like that of glacier grains. From these observations it seems safe to conclude that under normal atmospheric pressure the orientation of ice crystals is determined by the position of the original surface or center of refrigeration, consequently the orientation of glacier grains is determined by the position of the crystal axes in the original snow and névé grains.

As originally shown by McConnel and later more fully formulated by Mügge and confirmed by the experiments of Tarr and Rich, an ice crystal is made up of molecularly thin, flexible laminæ lying in a plane normal to the principal axes. Under pressure, with the ends of the principal axes supported, these laminæ will glide over one another and this gliding property may account for such uniform orientation of ice crystals in the basal layers of glaciers as may exist. It can not be assumed that such uniformly oriented crystals develop and grow in the direction of least resistance, in ice masses under pressure, for similarly orientated mica flakes in slates and schists which are presumed to have grown under like conditions are distinctly tabular, whereas the uniformly oriented glacier grains are not described as having any greater basal diameter than adjacent ones that are irregularly oriented. On the other hand, it is quite possible that the presence of a number of similarly oriented crystals may be the result of shear along the gliding planes brought about by differential pressure in the general direction of the movement of the glacier. Regrowth of the two parts of an individual crystal completely separated by such shear would result in adjacent crystals with similar orientation. This is in accord with Emden's contention that the essentially progressive growth of glacier grains from the névé to the ends of glacier tongues results from the absorption of small granules by adjacent larger ones, and with Deeley's assertion that the growth of glacier grains results from the transference of molecules from crystal to crystal under differential pressures in the ice.

Water is at its maximum density at a temperature of 4°C. and between that temperature and the freezing point, 0°C., it

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*Emden, Robt.: Uber das Gletscherkorn, Denkschriften d. schweiz. naturf. Ges., xxxiii, Zürich, 1892. Separates published by Zürcher and Furrer, Zürich.

has been suggested that the liquid phase consists of a mixture of ice molecules (H_6O_3) and water molecules (H_4O_2). Similarly it is quite possible that a residuum of water molecules exists in the solid phase, ice, at temperatures below, but near the freezing point. As the change from the liquid phase, water, to the solid phase, ice, is accompanied by expansion it follows that compression of the ice will result in the lowering of its melting point. Under uniform pressure this has been experimentally determined to amount to ·00722°C. per atmosphere of pressure. Johnston and Adams * contend that what is ordinarily termed the compression of solids is resolvable into uniform pressure and shearing stress. They further insist that permanent deformation of crystalline aggregates results from the effects of non-uniform pressure or shearing stress and that such deformation is occasioned by the real melting of those particles that at any instant bear the brunt of the load. On this basis they assert that non-uniform pressure lowers the melting point of ice ·09°C. per atmosphere of pressure. Considered in connection with the possibility of a residuum of water molecules in ice at temperatures near the freezing point this concept of the nature of compression effects on solids suggests the probability of a considerable volume of water being evolved by moderate pressure on ice at or near the freezing point temperature and such an effect has been noted by Hess † in exact experimental studies.

Ice masses do not consist of single crystals but, as shown above, of aggregates of comparatively small units variously oriented. The resistance of such masses to deforming stresses would appear to be due to three factors: (*a*) the nature of the interlocking of the units, (*b*) the molecular cohesion of the ultimate particles of a unit crystal, (*c*) the molecular cohesion existing at the contact of adjacent crystal faces. It follows that experimental studies of ice under compression with reference to glacial phenomena should be directed toward ascertaining the behavior of ice as a crystalline aggregate rather than to the investigation of the physical properties of unit crystals.

That there is a very considerable difference between the value of molecular cohesion of the particles of a unit ice crystal and that between particles of adjacent crystal faces is indicated by the differences in crushing strength exhibited by the pond ice put under compression (a) with principal axes of the component prisms parallel to the pressure direction and (b) normal to it, the crushing strength in the second case being

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* Johnston, J., and Adams, L. H.: On the Effect of High Pressures on the Physical and Chemical Behavior of Solids, this Journal, xxxv, 205, March, 1913.

† Hess, H.: Über die Plastizität des Eises, Annalen der Physik, (4), xxxvi, pp. 449–492, 1911.

only one-third that of the first. In the first case the load is borne by the columns of basal plates of the ice crystals, in the second it is transmitted through the mass along the adjacent parallel planes of the crystal prism faces. That the interlocking, irregularly oriented, crystals of glacier ice supported loads of intermediate value lends further confirmation to this deduction. In this connection it is interesting to consider the experiment with the pond ice under compression in the unyielding cylinder which resulted in the complete recrystallization of the ice with principal axes normal to the pressure direction, involving a rotation of 90°. If it be assumed that films of water were produced by non-uniform pressure or shear melting, in the initial adjustment of the mass to the load, then, since ice is of less density than water, it would follow that the stable condition under pressure would be such that the load was carried by the water, and that the water be of minimum volume and maximum bearing surface. This condition seems to have demanded the reorientation of the ice crystals with principal axes normal to the pressure direction.

Ice exists under natural conditions at temperatures near its melting point, hence change of phase due to increasing pressure or temperature is readily initiated and the velocity of transformation is quite high. Furthermore, as suggested in an earlier paragraph, residual water molecules may coexist with the polymerized ice molecules at temperatures near the freezing point. These relations would appear to have an important bearing on the plastic yield obtained in our experiments when cubes of pond ice with principal axes parallel to the pressure direction, and cubes of glacier ice, were subjected to pressures approximating the crushing strength, applied slowly. At the air temperatures at which the experiments were made these pressures were not great enough to induce melting by uniform pressure (·0072°C. per atm.) but would induce internal melting by non-uniform pressure, the effect of which is 12 times as great according to Johnston and Adams. As our bearing surfaces could not have been ideally plane-parallel, some portions of the ice must have borne a considerably higher load per unit of area than was registered by the scale of the press. Hence it seems quite probable that the yield achieved was due to internal liquefaction of the ice. The continuance of the yield, once started, with slightly diminished pressure and increased surface area would be ascribable to the fact that deformation of the cube would tend successively to exaggerate the localization of the whole load on certain small units of the bearing surface. Flow once started would also be facilitated by gliding movement between the basal plates of the ice crystals. On release of pressure the dissociated ice molecules (water) developed in the crystal structure would, owing to high reaction velocities, readily change back to the solid phase and thus preserve the ice clear and coherent throughout.

The lower molecular cohesion of ice masses along the contact planes of adjacent crystals, as indicated by the lower crushing strength, suggests that such internal liquefaction as occurs under non-uniform pressure may be localized between the crystal units and also between the basal plates of the single crystals. Such a deduction is corroborated by other evidence, and this leads to some very interesting conclusions regarding the structure of ice aggregates. These can best be presented by first considering the premises on which they are based.

Practically all natural waters carry considerable quantities of dissolved mineral salts. It is to be expected, therefore, that such material will be to some extent incorporated in ice formed on ponds, lakes and rivers. In large part, these soluble mineral salts in land waters are leached from rock substance. In the case of glacier ice, however, there is little or no opportunity for the incorporation of such material if it must be derived from rock leaching. But one of the commonest soluble salts, sodium chloride, in natural waters, is for the greater part not derived from rock leaching but is carried by the wind during storms as fine dust particles from the ocean and local salt deposits to points remote from its origin. The difficulty of accounting for the chlorine in inland waters and the well-known excess of chlorine in the ocean are the facts responsible for investigations that have shown, e. g., that in England at Cirencester an average annual deposit of 36·1 lbs. of sodium chloride has been for 26 years brought by the wind to each acre of surface. Hence there is no difficulty about the incorporation of a considerable quantity of this salt in glacial ice. Moreover, it is suggestive that the regions of present day notable glaciation are almost without exception favorably located for receiving supplies of wind-borne salt, directly from the ocean, from saline basins and from the surface of sea ice.

An aqueous solution of sodium chloride will completely crystallize at its eutectic point, —22°C., forming what has been termed cryohydrate, a mixture of salt and ice crystals, each distinct, in the proportions 23·5 per cent NaCl and 76·5 per cent H_2O. If the solution is originally more dilute than these percentages the excess of water crystallizes out progressively with fall of temperature until the eutectic concentration is reached at —22°C.

As pointed out above, sodium chloride must be carried by the winds in appreciable quantities to the snowfields of glaciers. In the change from snow to granular névé a process akin to the freezing out of the excess of water in the dilute aqueous solution must take place and the salt content of the snow concentrated in films between the névé granules. If the temperature of the névé is at or below —22°C. these films will consist of the cryohydrate solid. But as it is unlikely that so low temperatures as —22°C. exist far below the surface in any glacial masses it is much more probable that liquid films of salt solution develop between the pure ice granules and that this salt solution is of a concentration, therefore a thickness, dependent on the temperature and the size of the pure ice granules. At comparatively high temperatures, i. e., near the freezing point of pure water, a comparatively dilute solution must remain in the liquid phase. Again, the smaller the ice grains the greater their total surface area, consequently the thinner the film of salt solution that surrounds each at a given temperature. Since glacier grains are generally observed to increase in size from the surface toward the interior and from the head to the terminus of an ice tongue and the temperature of the interior ice to approach the pressure-temperature melting point, it follows that the interstitial films of salt solution will be progressively thicker toward the lower end of the glacier.

Possibly, also, there is a tendency for the salt solution to drain away from the surface zone of the ice and to be concentrated in the interior below the limiting depth of crevasses. Except then as the films of salt solution are held by capillarity the surface portions of the ice will be made up of ice grains that are very closely adjacent whereas there will be a corresponding concentration of the liquid films between the grains at greater depths.

Other investigators have argued the presence of saline solutions between the pure ice crystals of glacier and pond ice. Buchanan* points out that rain and snow contain seven parts per million of chlorine and that when glacier ice has a temperature as high as —0·07°C. it will consist of 1 per cent liquid brine or water. To the presence of such films he ascribes the effect of the sun's rays in disarticulating granular glacier ice and in developing the Forel lines that mark out the basal plates of the ice crystals. Thick pond ice similarly becomes "rotten" after a spring thaw and breaks up rapidly because it is disintegrated by melting in the planes of such films. Quincke† characterizes glacier grains as "foam cells" filled with pure ice and separated one from another by walls of "oily" salt solution. The origin of the salt solution he ascribes

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*Buchanan, J. Y.: In and around the Morteratsch Glacier, Scot. Geog. Jour., xxviii, pp. 169-189, 1912 and other earlier papers.

†Quincke, G.: The Formation of Ice and the Grained Structure of Glaciers, Nature, lxxii, pp. 543-545, 1905.

to the disintegration of rock debris incorporated in the ice. He accounts for the gliding planes of ice crystals, the development of Forel's stripes and of capillary fissures in the ice, on the basis of the presence of such films of salt solution. Elsden* endorses the same idea, quoting Buchanan.

On slowly melting and evaporating, in the experimental laboratory, at air temperatures near and below the freezing point, the ice crystals of the compressed ice cylinders were individually marked out by well-defined grooves. A block of glacier ice (from the Illecillewaet Glacier, Canada) similarly preserved showed the same phenomenon. Like grooves commonly develop on the surface of cakes of artificial ice slowly melting in refrigerators and if such ice is split with a sharply pointed ice pick it will be found that the mass will commonly break up into prismatic crystals, the grooves marking the surface outcrop of the crystal boundaries. The fact that in all these cases the grooves have a considerable width, from 1/32 inch to 1/16 inch, shows that the volume of the separating films is quite appreciable. The fact that these grooves develop on melting slowly in air temperatures near the freezing point indicates that the melting point of the interstitial material is lower than that of the bulk of the granules. It does not follow, however, that the width of the grooves is an index to the thickness of the interstitial films in the interior of the ice, for a very dilute salt solution would be very effective in developing a channel by melting at the surface in contact with air at temperatures above the normal melting point of pure ice. In the interior of the ice the film is probably much thinner and the solution more concentrated than in the outcropping grooves.

Before the writer knew of the writings of Buchanan and Quincke his attention was called to the possibility of there being different solubilities at the centers and peripheral zones of glacier grains by phenomena attendant upon the melting of icebergs from Alaskan tidal glaciers in sea waters. On the surface of those portions of berg that had been melting below the sea-water surface a unique "hammered silver" effect developed. (See fig. 8.) The centers of each of the polygonal ice grains were hollowed out and these concave depressions met in ridges where the grains came in contact with their neighbors. The ice under such surfaces was solid, transparent, clear blue. When, however, such bergs melted in the air (after stranding at low tide) the surfaces became smooth, the ice lost its transparency, the grains became disarticulated, colored solutions could be filtered through the intergrain fissures and the surface of the grains became marked with an arborescent sys-

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*Elsden, J. V.: Principles of Chemical Geology, London, 1910, p. 136.

tem of grooves. Apparently the melting of the ice in air and sea water is diametrically opposite with respect to the relative rate of the process at the centers of the grains and their intercrystal zones. The theory of the common ion seems best to fit the case of melting under sea water. In solutions so dilute that dissociation is approximately complete, the solubility of a given electrolyte will be lowered by the addition of a solution containing an ion common to it and the electrolyte, and conversely, the solubility of one salt may be increased by the presence of another salt not containing a common ion. The sea water contains dissociated Na and Cl ions, hence the solubility of the saline interstitial film is decreased while that of the pure, H_2O, ice crystal centers is increased. The development of the "hammered silver" surface by such differential solubility probably requires the maintenance of favorable and rather delicate equilibrium of temperature in that the sea water needs to be at or near the freezing point of fresh water.

Fig. 8.

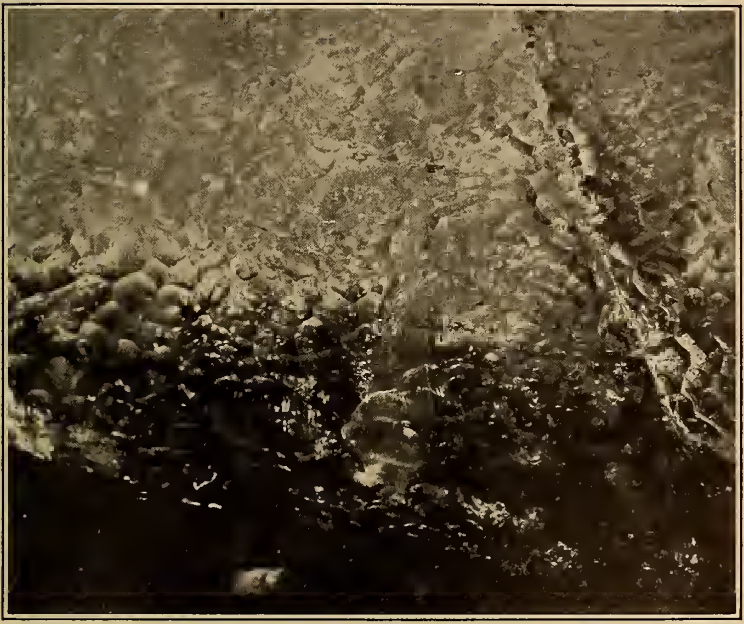

Fig. 8. Iceberg, stranded at low tide, with "hammered silver" surface developed by melting in sea water. Note the polygonal granules hollowed at the center. Photographed Aug. 2, 1909, Yakutat Bay, Alaska.

Since the sea surface in the region (Yakutat Bay, Alaska) where these observations were made is often quite completely covered with floating ice, this temperature relation is not impossible of attainment,—its existence was in fact confirmed by thermometric observations by the writer in 1909. Incidentally, if the theory of the common ion does apply to the phenomenon, as here suggested, the "hammered silver" berg surfaces afford a most striking and interesting natural example of the action of a comparatively little known principle.

The application of the experimental and other observations considered above to the structure and flow of glaciers has considerable significance. In the first place the position taken by the late Professor Tarr, that experimentation with ice to have a bearing on glacial phenomena must be done on ice aggregates and not on single crystals, seems to be borne out by the evidence indicating the presence of an interstitial film of saline solution between ice grains. The crushing strength tests on the cubes indicate that at sufficiently low temperatures crevasses may extend approximately 2000 feet deep from the surface without closing by flow. Hence it is apparent why the upper zones of glaciers seem quite brittle.

The development of crevasses to the maximum depth of 2000 feet would, however, necessitate lower temperatures than the evidence at hand shows to exist in the interior of glaciers. Hess and Blümcke* bored holes to a maximum depth of 153 meters in the Hintereisferner glacier. They found that the temperature of the interior ice was only so much below the melting point, under atmospheric pressure, as would be brought about by the pressure of the superincumbent ice masses at any given depth. Moreover, the temperatures at different depths were very closely accordant with the calculated depression of the melting point by a column of ice of that height. On the other hand J. Vallot† observed a constant annual temperature of −16·6° in the névé snow of the summit of Mont Blanc at a depth of 10 to 13 meters below the surface. As the snow from the highest parts of the névé field is that which eventually constitutes the bottom layers of a valley glacier, and as the deeper ice has progressively lower temperatures on account of the pressure relations, it would appear that the bottom of a glacier constitutes its coldest portion, also the thicker an ice tongue the lower its interior temperatures may be. But the factors that would need to be considered in an attempt to deduce the body temperatures of an ice tongue of large size are so various that a discussion of them would need to be long

*Hess, H.: Die Gletscher, pp. 151–153 and pp. 319–320. Later 200 meters depth was attained with same results.

†Quoted by Hess, H.: Die Gletscher, p. 164.

to be at all adequate. The average annual temperatures of the snow fields vary according to latitude and elevation. As snow is a poor conductor of heat it may be that quite low temperatures are imparted to the body of the glacier from its upper reservoir sources. Whether, during the course of its movement from the névé source to the end of the tongue, there is enough inflow of earth heat at the bottom of the ice to bring it to the pressure-temperature melting point would depend on the original degree of cold, the length of the glacier's course and its rate of flow. In any event, earth-heat would tend to raise the temperature in some measure. Since below the névé line sufficient heat is supplied to melt some of the ice, it follows that the surface temperatures of a glacier in summer must be at the melting point. The amount of surface melting is representative of the excess of heat supplied over that capable of being conducted from the surface, at the melting point, to the colder masses of the interior ice. Such conduction will continue until the interior portions have the temperature of the pressure-determined melting point. But as the near-surface portions will acquire this temperature earlier than those at greater depths, the conduction of heat to the deeper interior parts will be progressively slower from the surface downward. In other words, an increasing proportion of the excess heat will be utilized in near-surface melting. Thus, while in small glaciers, like the Hintereisferner, pressure-temperature equilibrium may be established for a considerable thickness of the ice tongue, it does not follow that this is the case for all the mass of glaciers of great thickness. Yet it may be concluded that, while it is by no means certain that the bottom temperatures of great ice masses are at the pressure-temperature melting point, it is improbable that they exhibit any extreme degree of cold.

Vallot found that the process of glacier-granule growth was distinctly in evidence in the névé of Mont Blanc at depths 10 to 13 meters below the surface (hence below the zone of surface water infiltration) where constant annual temperatures of −16.6°C. prevailed. Emden* has clearly demonstrated that ice granules as large as hazel nuts may be grown from originally small, snow-slush nuclei, kept in sealed vessels for several weeks at a constant temperature of 0°C. This growth he contends is due to the absorption of small granules by adjacent larger ones with consequent molecular readjustment. Deeley† also insists that the growth of glacier grains results from the transference of molecules from crystal to crystal under differential pressures.

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*Emden, R.: Uber das Gletscherkorn, Denkschriften d. schweiz. naturf. Ges. xxxiii, Zürich, 1892. Separates published by Zürcher and Furrer, Zürich.

†Deeley, R. M. and Fletcher, G.: Structure of Glacier Ice, Geol. Mag., Decade IV, ii, p. 155, 1895.

Under these conditions of progressive granular growth it is readily perceivable how the segregation of pure ice nuclei from the saline interstitial films takes place. Moreover, on the basis of the evidence stated above it seems unlikely that the body temperatures of glacier ice are very low. Hence, with only the development of comparatively slight pressures, through continued accumulation of snow above, it would appear that the growth of granules would be much facilitated and the flow of the ice initiated. That ice can be completely recrystallized under comparatively moderate pressures (1400 lbs. per sq. in. or less ; equivalent to an ice column about 3500 feet high) at air temperatures a number of degrees below the freezing point (−4°F. to 20°F.) was shown by the compression experiment with the unyielding copper cylinder. Moreover, the crystals developed were of quite large size showing that the velocity of the reaction is great; in other words, large crystals can grow in a short time. The permanent deformation by flow of the ice cubes under pressures approaching their crushing strength (650 to 1000 lbs. per sq. in., equivalent to an ice column 1600 to 2500 feet high) clearly demonstrates the ability of ice to yield plastically under differential pressure without disintegration and at temperatures a number of degrees below the pressure-melting point. Such yield may be in part due to shear, but in accordance with the known properties of the ice crystals can be more certainly ascribed to internal liquefaction in the planes of the basal gliding plates. The cause of this readier yield or gliding in the basal planes in turn may find its explanation in the presence of a residuum of saline material between the basal plates of the crystal as argued by Buchanan and Quincke. Another possibility is that it is due to an increase, under pressure, in the volume of water molecules (H_4O_2) included with the polymerized ice molecules (H_6O_3) in the solid phase, ice, at temperatures near the transition point, with consequent lessened viscosity or internal friction between the crystalline particles. Whatever the explanation, it is clear that such yield would account for the continuous deformation of even quite cold ice at great depths below the surface in the bottom zones of large glaciers.

That the lubricating effect of the saline interstitial films, increased in volume under pressure, and of the plastic internal yield described above, amply suffice to promote the free flow of ice without loss of coherence, was proved by the experiment in which the ice rod was caused to emerge from the lateral orifice of the rod cylinder to a total length of 16 inches.

Moreover, the fact, that, while at the beginning of the flow the temperatures were low, pressure relatively high and the emergence slow, in its later progress when pressures were much lower and temperatures higher the flow was much more rapid, indicates that with temperatures near the pressure melting point the yield of the ice is much easier and also, as shown by the experiments with the cubes, that flow once initiated continues under diminished pressure. This latter principle seems to be an important factor in that, applied to glaciers, it explains the rapid waves of advance accompanied by a swelling of the glacier tongues that have been noted in Alaska* and elsewhere.

A conception of the flow of glaciers as developed from the results of the experiments and consideration of the constitution and physical properties of glacier ice does not permit of characterization as either plastic or viscous. It is a plastic flow in the sense that the ice mass as a whole is permanently deformed by the movement, but its component grains are not subject or capable of such plastic deformation except in one direction and this appears to be a minor factor. Much more important is the movement that seems to be conditioned by the presence of the interstitial film of low freezing liquid, which may be characterized as viscous movement, by analogy like that of a stiff cement-concrete mixture.

From this point of view the glacier grains must be regarded as the rock-fragment units of the concrete mixture and the interstitial film as the liquid cement or lubricating substance diminishing the inter-unit, hence internal friction between them, thus facilitating movement analogous to that between the molecules of a viscous solid.

It may be questioned whether the volume of the interstitial film can be sufficiently great to permit of the degree of articulation between the ice grains required for continuous flow without involving the distortion or destruction of the crystalline units, hence preventing their progressive growth in size from the upper to the lower portions of an ice tongue. In this connection a calculation by Chamberlin† is interesting. He figures that in the interlocking, granular portion of a glacier six miles long, with a movement of three feet per day, an individual granule would need to move the length of its own diameter, with reference to its neighbor, only once in thirty years. On this basis it would appear that only a very slight thickness of interstitial film in the liquid state would be required to permit of all necessary readjustments between the crystalline grains, while keeping their interlocking structure intact and permitting their growth in size. Where differential pressures exist and an accelerated local flow is demanded this will be

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* Tarr, R. S.: Recent Advance of Glaciers in the Yakutat Bay Region, Alaska, Bull. Geol. Soc. Amer., xviii, pp. 257–286.

† Chamberlin, T. C.: A Contribution to the Theory of Glacial Motion. Decennial Publications of the Univ. of Chicago, Chicago. First series, vol. ix, p. 201, 1904.

facilitated by an accompanying increase in the volume of the interstitial film in that area.

Summarizing, the phenomena of a valley glacier may be conceived as follows. In the reservoir area the increasing depth of accumulating snow gradually augments the pressure on its bottom layers. In the mass, meanwhile, the growth of ice crystals proceeds by molecular transference of particles and the absorption of small grains by adjacent larger nuclei. At the same time the saline matter is being segregated in the intergranular spaces. Compression itself involves a rise in temperature and such rise is further increased by inflow of surface heat and heat from the earth. When pressure and heat attain sufficiently high points flow is initiated. During the period of snow accumulation the snow and ice mass in the reservoir is under practically uniform pressure. Once flow is started non-uniform pressures are introduced with resulting increases and decreases of the thickness of the interstitial films.

The continued movement of the ice tongue so started results both from the pressure due to its own thickness and thrust from the continuation of the tongue up slope. If the snow supply in the reservoir is cut off an equilibrium of pressures will be established and the glacier will then melt away without further flow. If the snow supply is insufficient to provide great enough accumulations for continuous flow pressures, there will be alternative waves of advance and stagnation. Apparently the latter condition is only attained under exceptional conditions because flow is more readily maintained than initiated.

The surface portions of the ice tongue are relatively rigid and brittle. The viscous (?) underflow gives rise to tensional and shearing stresses in the upper, rigid ice layers with resultant crevassing. These crevasses are commonly developed on a greater scale in the upper ice tongue, partly because slopes are steeper, partly also, probably, because the ice of the upper portions of the ice tongues is colder. In the lower expanded portions of ice tongues pressure-temperature equilibrium has been established throughout the thickness of the ice, hence flow is possible over lower slopes and with thinner ice than at and above the névé line. Near-surface melting in the lower parts of the tongue is localized in the intergranular spaces, the resulting water tends to drain away and thus leaves the ice grains "loose in the socket." On the bottom of the glacier, near the very front, the establishment of pressure-temperature equilibrium combined with the continued inflow of earth-heat and friction may result in pressure melting and thus give rise to submarginal glacial streams, whose volume is augmented by the surface-melting water percolating through the frontal portions of the crumbling ice tongue or finding its way to the bottom through crevasses and moulins.

In the middle portions of the flowing ice tongue three separate zones may be conceived as existing from the surface to the bottom. At the top is the brittle, crevassed mass, below it the viscously(?) flowing ice, and under that a colder ice layer, continuing to the bottom, which is being plastically (?) deformed by reason of the pressure of the overlying ice and the frictional pull the viscous intermediate layer is exerting on its upper surface. On this basis a decreasing rate of flow from the surface to the bottom of a glacier could be accounted for, and a greater erosive power could be ascribed to the relatively more rigid, colder bottom layers.

Future Experimentation.—It would be very interesting to freeze a number of blocks of ice from saline solutions of progressively increasing density and slowly melt them, noting the relative development of the inter-crystal grooves. Where glacier ice is accessible the relative concentration of saline material in the granules and in the interstitial spaces might be tested by picking out a number of granules, washing them with distilled water and then analyzing them for salt content in comparison with a coherent mass of glacier ice. It would also be worth while to attempt the compaction of snow into ice under long-continued pressure and cause this to flow from a lateral orifice. This experiment the writer hopes to attempt in a succeeding winter.

Geological Department, Physiography Laboratory,
Cornell University.

ART. XXXIII.—*A Mounted Specimen of Dimetrodon incisivus Cope, in the University of Michigan*; by E. C. CASE.

IN 1912 the author discovered the Brier Creek Bone Bed in Archer County, Texas. This bone bed in the Wichita Formation of the Permo-Carboniferous deposits of northern Texas contained, by far, more bones than any known accumulation of the same age. Over 1500 specimens of separate bones were recovered, and many times that number would have been taken had not a large proportion of the material been ruined by the infiltration of iron-bearing waters which rotted the bones and cemented them together in an inseparable mass.

FIG. 1.

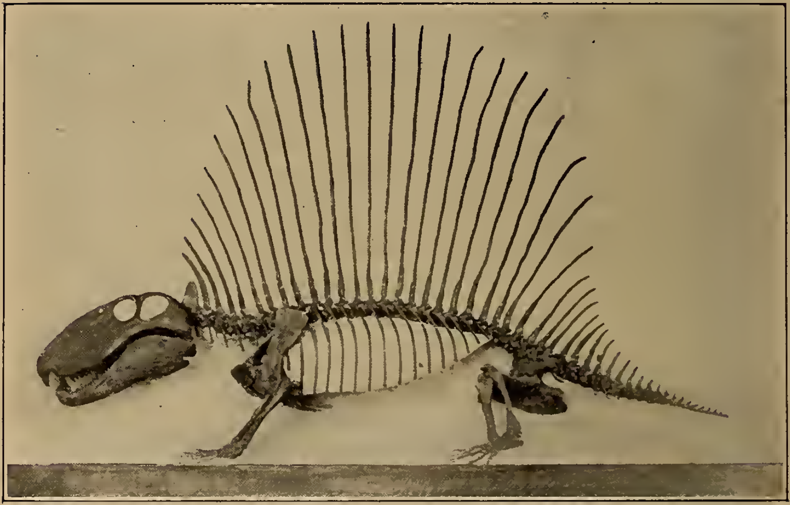

FIG. 1. Photograph of the mount of *Dimetrodon incisivus* Cope. × ·055.

A complete description of this bed and of the new forms discovered has been given by the author in Publication No. 207, Carnegie Institution of Washington, 1915. Though most of the bones were isolated, due to the complete maceration of the bodies and the later movements of the material in the swamp or muck-hole in which they were imbedded, some partially complete skeletons were recovered, among them the nearly complete skeleton of an *Edaphosaurus cruciger* Cope, which has been partially cleaned and will be mounted in the University of Michigan next year.

From the very abundant material sufficient bones of the right size have been selected to mount a nearly complete skeleton of *Dimetrodon incisivus* Cope. The work of mounting this specimen necessitated a careful study of the possible attitudes and movements of the animal which is reflected in the completed work. The skull in the mount is restored in plaster, except the anterior portion of the lower jaws, from fragments in the collection and from careful studies upon the perfect specimen of a skull of this species in the American Museum of Natural History in New York and upon a very perfect specimen of the skull of *Dimetrodon gigas* in the possession of the author. The notably large size of the skull led to a very critical study of the proportions to check the apparent incongruity and the author feels sure that the proportions shown in the skeleton are correct. As mounted, the skull is raised slightly from the ground but is still inclined somewhat downward in an attitude of partial repose. From the position and character of the cervical vertebræ it is apparent that the head could not have been raised very much higher, except as it was violently forced upward in a moment of anger or attack.

Fig. 2.

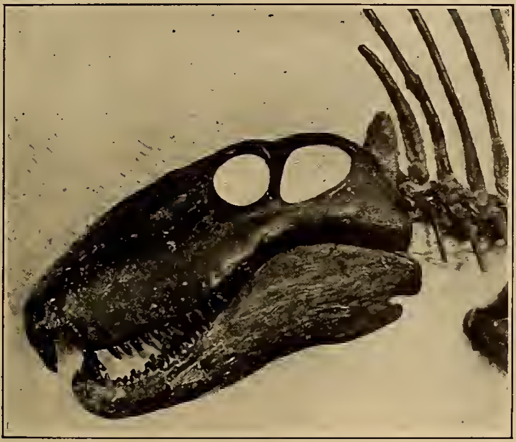

Fig. 2. Photograph of the restored skull, all plaster except the anterior portion of the lower jaw, with the teeth. × ·13.

The body is placed in an attitude of repose; the posterior end of the interclavicle rests upon the ground and the symphysis of the pubes is raised only sufficiently to allow for the cartilages which were present during life. In this attitude the spines were in the most relaxed position, and they have been mounted in the most regular position and arrangement permitted by the condition of the spines and the vertebræ to which they are attached. There can be little doubt that the position of the spines varied in each individual and were not infrequently distorted by injuries, so the position given in the mount is probably as correct as may be.

Notable is the sudden increase in height of the spines in the cervical region and the almost equally sudden decrease in height in the sacral and anterior caudal region.

FIG. 3.

FIG. 3. Photograph of the skull of *Dimetrodon gigas* Cope. × ·21.

FIG. 4.

FIG. 4. Photograph of the fore limb and shoulder girdle. × ·16.

The shoulder girdle is mounted nearly complete; the interclavicle, the clavicles, the scapula of the left side complete, and the lower part of the scapula of the left side all being in plain view and as free as their support permits. Though a slight distortion of the bones makes the exact outline of the shoulder-girdle somewhat uncertain, the author believes that the departure from the normal curvature is very slight. No cleithrum has been placed in the mounted skeleton as no bones which could be referred to this element was found in the abundant material.

The humerus is placed in an almost exactly horizontal position, extending directly outward from the cotylus. It is evident from the position of the scapula and its cotylus that the

Fig. 5.

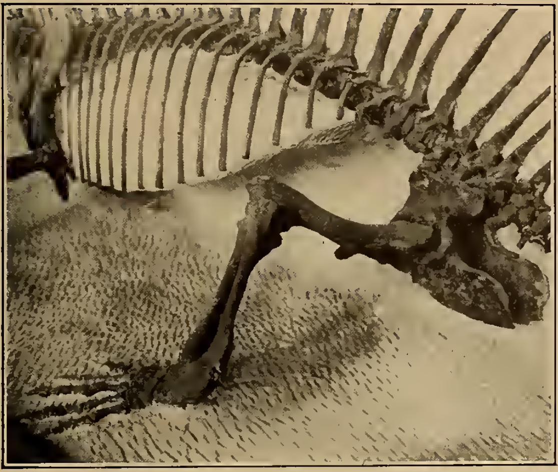

Fig. 5. Photograph of the posterior limb and pelvic girdle. × ·2.

Fig. 6.

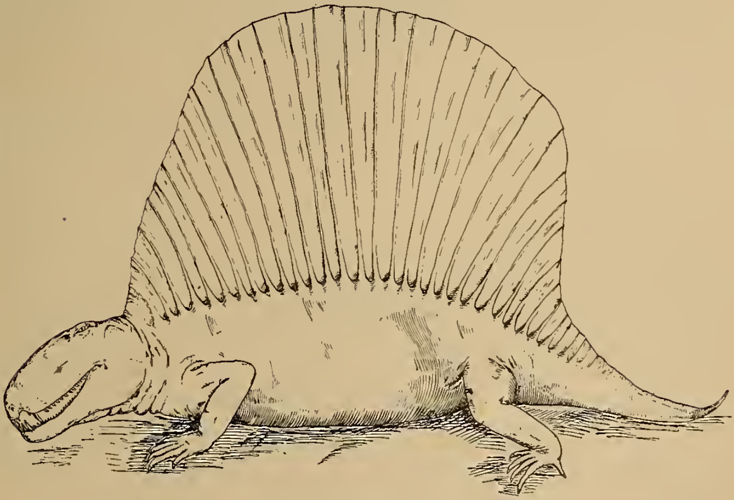

Fig. 6. Restoration of *Dimetrodon incisivus* Cope. The line of the back is a little too curved. × ·05 about.

motion of the humerus was closely restricted to a plane parallel with the ground.

The pelvis is complete and mounted nearly free, being attached only by the outer side of the right half: this leaves the whole sacral series of vertebræ open to inspection. The posterior limb is placed with the femur pointing slightly upward and forward; this is rather the conventional than the usual resting attitude of the creeping reptiles, but is not an impossible or even an unusual attitude.

The carpus and tarsus are modeled in plaster; the first after the well-preserved carpus discovered by the author some years ago and now in the possession of the University of Chicago, and the tarsus, except for the astragalus, calcaneum and centrale 2, after the primitive type of the reptilian carpus. Elements of both carpus and tarsus are not lacking in the collection but were not included in the mount because of the impossibility of assembling sufficient bones of the correct size.

The ribs are all restored in plaster after well-authenticated specimens.

The tail has been made relatively short in consonance with the ideas of the author, but as no specimen has yet been discovered in which the tail is complete the exact number of vertebræ is uncertain.

The completion of this mount is the first attempt to assemble all parts of the skeleton of *Dimetrodon* in a natural posture. Its accomplishment is largely due to the patience and skill of Dr. E. L. Troxell, who, as preparator, coöperated with the author in assembling and placing the bones.

ART. XXXIV.—*A Fossil Ruminant from Rock Creek, Texas, Preptoceras mayfieldi sp. nov.*; by EDWARD L. TROXELL.

AMONG the very abundant fossil remains found at Rock Creek there was the skull of a ruminant, and possibly belonging to it were an atlas and some rib fragments. Associated with these bones were parts of *Elephas*, *Mylodon*, *Auchenia* and *Equus*, representing the fauna of the early Pleistocene.

The skull resembles somewhat that of the ox, especially in the general form and position of the horns, which come out in the plane of the face, trending upward, then downward and forward. At first it was taken to be the skull of a sheep, but it is found to be very different. It is about one-half larger than a skull of *Ovis rockymontanus* and the horns, which are not so large, do not curve backward nor are they set close together. It is probably allied to a specimen from New Mexico, viz: *Liops zuniensis* Gidley.* But of all known skulls it resembles most that of *Preptoceras sinclairi* Furlong † from the caves of California. It is, therefore, put under that genus.

FIG. 1.

FIG. 1. Posterior view of skull of *Preptoceras mayfieldi*, sp. nov. Holotype, Cat. No. 10920, Yale Museum (× ·25).

The new species is named in honor of Mr. Gidley Mayfield, on whose ranch the specimen was found. This is located

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* Proc. U. S. Nat. Mus., vol. xxx, 1906, pp. 165–167.

† Univ. of Cal., Bull. Dept. Geol., vol. iv, 1905, pp. 163–169.

about a mile from the famous quarry where ten skeletons of *Equus scotti* have been unearthed.

The horns of the new species arise from the frontal bones at an angle of about 90° to each other. The cores are slightly flattened antero-posteriorly and at the bases have burrs.

FIG. 2.

FIG. 2. Anterior view of skull of *Preptoceras mayfieldi*, sp. nov. Holotype, Cat. No. 10920, Yale Museum (× ·25).

FIG. 3.

FIG. 3. Posterior view of skull of the type specimen of *Preptoceras sinclairi*, after Furlong (× ·2).

The frontal bones form the crown and join the parietal well back on the head; the suture lies in general about one centimeter above the lambdoid crest. The parietal is not paired but, as in many Artiodactyla, was probably fused early in life. The frontal and squamosal form a deep groove on the side of the head, parallel to the suture, continuing into the orbit anteriorly and ending posteriorly at the ridge which lies along the side of the skull. The outer extremity of the lambdoid crest continues into this sharp ridge, which marks the union of the squamosal, parietal and occipital portion of the skull laterally, giving this region a flat appearance. The crest loops downward in its middle portion to join the central tubercle which formed the attachment for the nuchæ ligamentum—the chord which follows along the back of the neck. Two fossæ are observed on either side of this tubercle. They are shallow, however, since the lambdoid crest does not markedly overhang the occiput. The lambdoid suture below the crest is obscured.

The skull is very deep from a point between the horns to the occipital condyles and in general is very stout. The anterior portion is broken off just above the orbits. A slight rise in the frontals anteriorly suggests that the animal had a rounded forehead. The foramen magnum for the most part opens on the dorsal surface of the occiput.

Dimensions.	mm.
Inter-cornu space	75
Diam. of horn cores ant.-post.	74
" " " " transverse	85
Breadth of forehead, anterior to horns	144
Breadth of cranium, posterior to horns	92
Depth from point between horns to extremity of occipital condyle	167
Width of basi-occipital	55
Cranio-facial angle, about	45°
Occiput-facial angle, about	68½°

The specimen is placed in the genus *Preptoceras* because of the very great general similarity to the type. It differs from *Preptoceras sinclairi* in that its fossæ just beneath the lambdoid crest are not so deep; the lambdoid suture lies near this crest (this is like *Euceratherium*); the horns are smaller, less rounded dorsally and more widely separated; they do not come out "from the extreme posterior and lateral ends of the frontals" as in the type species but are situated three centimeters from the posterior and four from the lateral borders.

The present species differs very greatly from *Liops zuniensis*. The horns of the latter are set wide apart, come out straight from the skull and droop decidedly; they have no burrs on the horns, no true lambdoid crest and the skull generally is smooth in the extreme.

Ovis is frequently mentioned in the literature, but no authentic record of a true fossil sheep can be found earlier than what might well be considered Recent.

The atlas found associated with the skull and corresponding in size has some distinctly camel-like characters. The transverse foramen follows the wall of the lateral process and opens on the edge near the axial articulation. This articular surface is broad and flat and a wide strip extends beneath the neural canal. The atlas is over one third broader than that of a full grown camel, indicating a powerful neck. The animal must have been quite strong, for the skull also is heavy and the horns are large.

The occiput-facial angle as nearly as can be determined is 68½°, showing the great posterior extension of the crest or the low position of the condyles.

The facio-cranial angle is, roughly measured, 45°. Such a great deflection of the face is characteristic of the sheep and is indicative of a grazing adaptation. The angle increases with age but in the adult sheep goes beyond 50°. From the sutures, which are not closely knit, and from this angle the animal is considered as having almost reached maturity.

University of Michigan.

Art. XXXV.—*The Separation and Estimation of Aluminium and Beryllium by the Use of Acetyl Chloride in Acetone;* by H. D. Minnig.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—cclxxii.]

In a former paper* from this laboratory a method was described for the quantitative separation of aluminium from iron by the use of acetyl chloride in acetone. The application of this method depends on the fact that from concentrated aqueous solution of the two chlorides aluminium is precipitated completely as the hydrous chloride, while the iron remains in solution. This precipitation is brought about, doubtless, by the decomposition of the acetyl chloride and simultaneous formation of hydrochloric acid which, as is well known, is a precipitant for aluminium. At the same time the precipitating mixture furnishes organic liquids in which the precipitated hydrous chloride of aluminium remains insoluble and the chloride of iron soluble. The main function of the acetone is simply to abate the violence of the reaction which ensues when acetyl chloride reacts with water.

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* This Journal [4], xxxix, 197–200, Feb. 1915.

Commercial acetyl chloride can not be used in this work because of phosphorus compounds used in its manufacture, the last of which cannot be removed. This phosphorus contamination shows itself not only in the filtrate from the aluminium precipitate, but also in the aluminium precipitate itself, giving high results. The acetyl chloride was therefore prepared as described in the former article.* Acetic anhydride was distilled from a little anhydrous sodium acetate to remove contaminating phosphorus compounds. Tests for included phosphorus compounds were made by hydrolyzing the acetic anhydride with water, evaporating down with nitric acid to oxidize any trivalent phosphorus which might be present from the manufacture of the commercial product, and treating the solution with ammonium molybdate in nitric acid solution. The purified acetic anhydride was then saturated with hydrogen chloride and the product distilled at 100° C. in a rapid current of the same gas. Redistillation gives pure acetyl chloride.

The method of procedure was the same as in the separation of iron from aluminium. Measured portions of solutions of the two chlorides in small beakers were evaporated to the smallest possible volume on the steam bath. In case the evaporation proceeds to dryness it is well in dissolving the salts to add a drop of hydrochloric acid to prevent the formation of basic salts, particularly of basic beryllium chloride. The beaker containing the concentrated solution was then placed in a dish of cold water and the acetone-acetyl chloride mixture (4-1) was added drop by drop from a dropping funnel to the complete precipitation of the hydrous chloride of aluminium. Fifteen to twenty cubic centimeters of the mixture usually sufficed. The settling of the crystalline precipitate is a good indication, though not an infallible one, of the complete precipitation of the aluminium chloride. When the precipitation was judged to be complete, the precipitate was transferred to a weighed perforated platinum crucible and carefully washed with the precipitating mixture. The filtrate and washings were caught in a beaker under a bell jar. The precipitate was dried slowly, at first high above a low Bunsen flame and then gradually lowered until the full heat of the burner was obtained. The hydrous chloride on ignition leaves the oxide. The acetone-acetyl chloride solution of beryllium was copiously but cautiously diluted with water to avoid spattering, and the resulting solution in a beaker covered by a watch glass, was warmed gently on the steam bath until the volume seemed to remain constant, indicating that the easily volatile acetone had been removed. The solution was then boiled and ammonium

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* Loc. cit.

hydroxide added to alkaline reaction. The precipitate was allowed to settle, filtered, and treated as usual in determinations where beryllium is weighed as the oxide. Results of the experiments are given below.

SEPARATION BY ONE PRECIPITATION.

Al_2O_3 Taken as $AlCl_3$ grm.	Al_2O_3 Found grm.	Al_2O_3 Error grm.	BeO Taken as $BeCl_2$ grm.	BeO Found grm.	BeO Error grm.
0·0927	0·0933	+0·0006	0·0638	-----	-----
0·0927	0·0934	+0·0007	0·0638	-----	-----
0·0927	0·0943	+0·0016	0·0638	-----	-----
0·0927	0·0934	+0·0007	0·0638	-----	-----
0·0927	0·0931	+0·0004	0·0638	-----	-----
0·0865	0·0878	+0·0013	0·0561	0·0549	−0·0012

High results in the foregoing table seemed to indicate that beryllium chloride was being included in the aluminium precipitate, a circumstance which does not seem surprising in view of the marked similarity between the reactions of the two elements. A double precipitation of the aluminium was therefore tried. After the first precipitation the liquid was decanted through the filter, retaining as much as possible of the precipitate in the beaker. This precipitate in the beaker was washed four or five times with the precipitating mixture and finally dissolved in a small quantity of water. The excess of water was evaporated off and the process of precipitation repeated. The two filtrates were united and the beryllium determined as before.

SEPARATION BY TWO PRECIPITATIONS.

Al_2O_3 Taken as $AlCl_3$ grm.	Al_2O_3 Found grm.	Al_2O_3 Error grm.	BeO Taken as $BeCl_3$ grm.	BeO Found grm.	BeO Error grm.
0·0865	0·0869	+0·0004	0·0561	-----	-----
0·0865	0·0868	+0·0003	0·0561	-----	-----
0·0865	-----	-------	0·0561	0·0564	+0·0003
0·0865	0·0867	+0·0002	0·0561	0·0575	+0·0014
0·0865	0·0867	+0·0002	0·0561	0·0561	0·0000
0·0865	0·0865	0·0000	0·0561	0·0560	−0·0001
0·0865	0·0870	+0·0005	0·0561	0·0554	−0·0007
0·0865	0·0866	+0·0001	0·0561	0·0557	−0·0004
0·0865	0·0881	+0·0016	0·1122	0·1111	−0·0011
0·0865	0·0884	+0·0019	0·1122	0·1093	−0·0029
0·0865	0·0869	+0·0004	0·1122	0·1118	−0·0004
0·0865	0·0873	+0·0008	0·1122	0·1108	−0·0014
0·1730	0·1739	+0·0009	0·0561	0·0548	−0·0013
0·1730	0·1741	+0·0011	0·0561	0·0554	−0·0007

That there is danger of inclusion of beryllium chloride could readily be seen when the quantity of that substance was increased. Unless the progress of the precipitation was watched and the addition of the precipitating mixture stopped as soon as the separation of the crystalline aluminium chloride seemed to be complete, beryllium chloride could also be seen to separate out.* Its appearance is very unlike that of the aluminium chloride and can easily be distinguished. Even when the addition of the precipitating mixture was stopped before the formation of this salt became noticeable in the beaker, it appeared as soon as the supernatant liquid had been poured through the filter and an attempt was made to wash the precipitate. Increase in the quantity of aluminium chloride seems also to have a like effect because of the necessity for an increased volume of the precipitating mixture.

The comparative insolubility of beryllium chloride in acetone acetyl chloride (4-1) limits this process, therefore, to separation of quantities of the two elements present as the chlorides which do not exceed the equivalent of 0·15 grm. of the oxides. Of this amount beryllium oxide should not greatly exceed one-third.

The use of acetyl chloride as a substitute for hydrogen chloride simplifies very much the method of Havens† and therefore the favorable criticism of Noyes, Bray and Spear‡ ought to apply to this method as well as to that of Havens. These investigators found the method of Havens to be very reliable even when the amount of aluminium present was exceedingly small.

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*Probably the same compound mentioned on page 24 of Parson's book, "The Chemistry and Literature of Beryllium." That precipitate was obtained by the use of ether saturated with hydrogen chloride.

† This Journal (4), iv, 111.

‡ A System of Qualitative Analysis for the Common Elements, III, 19.

Art. XXXVI.—*On the Interferences of Crossed Spectra and on Trains of Beating Light Waves*; by C. Barus.*

1. *Introductory.*—If two component spectra from the same source coincide throughout their extent, the elliptic interferences will be spread over the whole surface, provided of course the respective glass and air path differences of the component rays are not too great to interfere with visibility. In the usual method of producing these interferences, where the corresponding reflections and transmissions of the two component rays take place at the same points of the same plane surface, the interference pattern is automatically centered, or nearly so. This is not the case when, as in the following experiments, the interfering beams are produced in some other way; and the problem of centering is one of the chief difficulties involved. But if the four beams are to be treated independently, it is difficult to obviate this annoyance.

Suppose now that one of the spectra is rotated around an axis normal to both, by a small angle. Will the interferences at once vanish, or is there a limiting angle below which this is not the case? In other words, in how far can one trench with light waves upon the case of musical beats or of interferences not quite of the same wave length?

Instead of approaching the question in this form, in which it would be exceedingly difficult experimentally, I have divided it into two component parts. Let one of the spectra be rotated 180° degrees around a *longitudinal* axis, parallel to the red-violet length of the spectrum and normal to the Fraunhofer lines. In such a case, interference should be possible only along the infinitely thin longitudinal axis of rotation to which both spectra are symmetrical, one being the mirror image of the other. One would not expect these interferences to be visible. It is rather surprising, however, that this phenomenon (as I have found) may actually be observed along a definite longitudinal band in the spectrum, about twice the angular width of the distance between the sodium lines and symmetrical with respect to the axis of rotation. It is independent of the width of the slit, provided this is narrow.

Again let one spectrum be rotated 180° about a given Fraunhofer line (*transverse* axis), the mean D line for instance. The two coplanar spectra are now mutually reversed, showing the succession red-violet and violet-red respectively. Interference should take place only along the D

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* Abridged from a forthcoming report to the Carnegie Institution of Washington, D. C.

line and be again inappreciable. Experimentally, I was not at first able to find any interferences for this case in the earlier manner shown below. But this may have been due to inadequacies in the experimental means employed: for the dispersion was insufficient and the reflecting edge of the paired mirrors too rough. Improving the apparatus, I eventually found the phenomenon, appearing however as a single line, vividly colored above the brightness of the spectrum; or again more jet black than the Fraunhofer lines and located in the position of the coincident wave lengths of the two superimposed spectra.

It is possible, however, as will be shown below, §4, to obtain two spectra in such a way that if their longitudinal axes coincide the Fraunhofer lines intersect at a small angle, and vice versa. In such a case, for coincident Fraunhofer lines, interference occurs in a band around these lines and is absent in the rest of the spectrum; whereas, if the longitudinal axes are coincident, the interferences are arranged with reference to these axes. These results seem to bear on the question, but it is difficult to clearly resolve it.

The methods used in this paper consist chiefly in bringing the two first order spectra, or the second order spectra or their equivalents, to interfere. In this respect they contain an additional method of interferometry which may be useful, if for any reason it is necessary that the two component beams are not to retrace their paths.

2. *Case of coincident spectra with one reversed on a given Fraunhofer line.*—In figure 1, *L* is a narrow vertical sheet (to be broadened by the diffraction of the slit) of white sunlight or arc light from a collimator, *G* the transparent grating ruled on the side *g* from which the first or second order of spectra *gM* and *gN* originate. *M* and *N* are opaque mirrors, mounted adjustably on a firm rail, *RR*, each of them with three adjustment screws relative to horizontal and vertical axes. *M* is provided with a slide micrometer (not shown). From *M* and *N* the beams pass to the smaller paired mirrors, *m* and *n*, which should meet in a fine vertical line at a very obtuse angle. A silvered biprism would here have been far preferable, but none having the required angle was available. From *n*, *m*, the beams pass into the telescope *T*. As the spectra are each divergent after issuing from *g*, they can be made to overlap on leaving *n*, *m*, by aid of the adjustment screws on *M N*. Moreover as the spectra are mirror images of each other, as suggested in figure 1, any spectrum lines (as for instance the *D*) may be put in coincidence on using one of the adjustment screws specified. It is necessary that the telescope *T* be sufficiently near *M* in order that the micrometer may be manipulated.

The D lines placed in coincidence are obviously opposites, each line being paired with the mate of the other. A fine wire must be drawn across the slit of the collimator, in order that the vertical coincidence may be tested. One should expect the interferences to appear between the D lines on gradually moving the micrometer mirror M, parallel to itself, into the required position. As stated above, I did not at first succeed in finding the interferences, but the experiment is a delicate

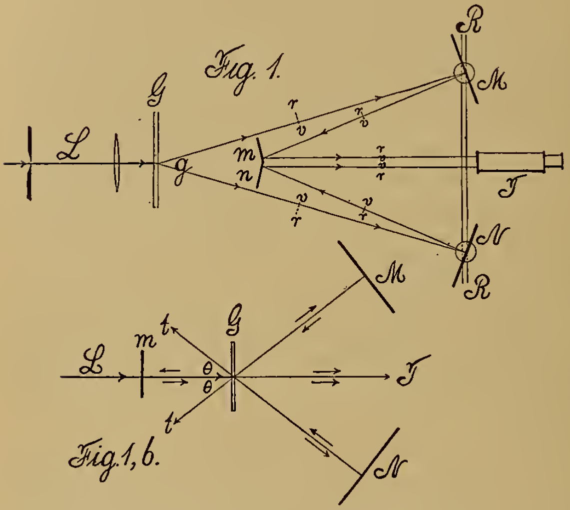


Fig. 1.

Fig. 1, b.

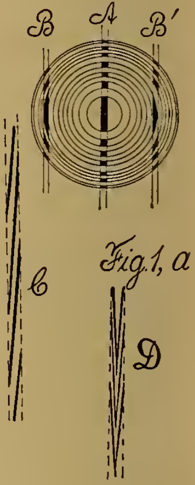


Fig. 1, a

one. In a repetition with first order spectra, it would be advisable to replace the plane mirrors m, n by slightly concave mirrors, about 2 meters in focal distance and to replace the telescope T by a strong eyepiece. This is the method used in the next paragraph and it was more easily successful.

Later I returned to the experiment with the same adjustment, except that the plane mirrors m, n were placed beyond the grating, with the object of using the equivalent of second order spectra to get more dispersion. This plan did not fail; and having once obtained the interferences, the reproduction seemed quite easy, as they remained visible while the micrometer M was moved over about ·50 cm. or more. Their appearance with a *small* telescope was that of a single fine line, alternately flaming yellow (very bright on the yellow background of the surrounding part of the spectrum) and jet black as compared with the D lines, between which the interferential line was situated. This flicker is referable to the tremor of the laboratory, which makes it impossible to keep these interferences quiet. Shutting off the light from either mirror, *M* or *N*, naturally quenches the interferences, but leaves the yellow part of the spectrum behind.

Obviously coincidence of the longitudinal axes of the spectra alone is needed. Therefore upon moving the two double *D* lines apart, by aid of the adjustment screws on the mirror *M* and *N*, symmetrically to the ends of the yellow field in the telescope, the interferences were isolated and located midway between the *D* doublets of each spectrum; i. e., in the center of the field of the telescope. They could now be observed to better advantage. In the small telescope there is apparently but one dark line, and if stationary, its character when centered would be surmised to be given by the intersection of a vertical diameter with a series of con-focal ellipses, successively bright and dark, as indicated in figure 1*a*. The light and dark parts alternate or flicker. On moving the micrometer, the vertical intersector *A* takes a more and more lateral position like *B*, so that the trembling interferences would soon be invisible as they rapidly become finer (not shown).

On using higher magnification (larger telescope), two black lines bordering a bright, or a black line between two bright lines, seemed to be visible; but the interferences would have to be stationary to be definitely described, since the width of the pattern is not more than 1/3 to 1/2 of the distance between the sodium lines. The interferences, moreover, did not now conform to the design *B*, fig. 1*a*, anticipated, but were more of type *C*, with the long dark lines very slightly oblique to the vertical, and vibrating within a vividly yellow band. Sometimes these were heavier with two or three faint lines on one side.

Further experiment showed that the phenomenon is not influenced by the width of the slit, except that it is clearest and sharpest with the narrowest slit possible and vanishes when the slit is made so wide that the Fraunhofer lines disappear. It may easily be produced by the modified method following in any wave length, red, yellow, green, etc., with no essential difference except in size. It is present moreover in all focal planes, i. e. the ocular of the telescope may be inserted or pulled out to any distance, yet the same phenomena persist on the vague, colored background. A number of observations were made to detect the change of the pattern of the interference between its entrance into the field and its eventual evanescence in case of the continuous displacement of the mirror *M*. In figure 1*a* this would be equivalent to a passage of *B* into *B′* through *A* and the fringes for a distant center should therefore rotate, as they actually do in the experiments of paragraph 4. But in the present case the type *C* persists, the lines may become longer or all but coalesce and their inclination may change somewhat. They nevertheless remain fine and nearly vertical until they vanish completely and there is no rotation. Nor could the phenomenon be found again within the length of the given micrometer screw. Hence it is improbable that these interferences conform at once to the ordinary elliptic type, even if the ellipse is considered exceptionally eccentric. The use of two slits, one following the other, does not change the pattern.

The modified method of experiment was one of *double* diffraction. In figure 1*b*, L is the blade of light from the collimator, which passing *under* the plane mirror m, penetrates the grating G whence the diffracted first order beams reach the opaque mirrors M and N. These return the beams nearly normally, but with an *upward* slant, so that the color selected intersects the grating at a higher level than L. A second diffraction takes place at the same angle, θ, to the direct ray t and the coincident rays now impinge on the mirror m. They are thence reflected into the telescope at T. This method admits of an easy adjustment, as everything is controlled by the adjustment screws on M and N and plane mirrors M, N, and m only are needed, the latter being on a horizontal axis to accommodate T. Directly transmitted white light is screened off.

3. *The same. Further experiments.*—In place of the plane mirror, m, a slightly concave mirror (two meters in focal distance, say) may be used with advantage and the telescope T replaced by a strong eyepiece. In this way I obtained the best results.

It is to be noticed that the apparatus, fig. 1, *b*, may serve as a spectrometer, provided the wave length, λ, of one line and the grating space, D, are known, and the mirror, M, is measureably revolvable about a vertical axis. In this case any unknown wave length, λ', is obtained by rotating M, until λ' is in coincidence with λ. Supposing the λ's of the two spectra to have been originally in coincidence and that θ is the angle of M which now puts λ' in coincidence with λ, it is easily seen that

$$\lambda' - \lambda = \lambda\,(2\sin^2\theta/2 + \sqrt{D^2/\lambda^2 - 1}\sin\theta).$$

Angles must in such a case be accurately measureable, i. e. to about ·1 minute of arc per Angström unit, if $D = 351 \times 10^{-6}$, as above. Counter rotation of the mirror N till the λ''s coincide would double the accuracy. The usual grating, however, has greater dispersion and would require less precision in θ.

Finally a still simpler and probably more efficient device consists in combining the mirror m and the plane grating G, or of proceeding, in other words, on the plan of Rowland's concave reflecting grating. In such a case the light would enter in the direction TG, fig. 1, *b*, be diffracted along GM, back along MG and then return along GT at a slightly higher or lower level than on entering. The equation just given would still apply and many interesting modifications are suggested. Experiments of this kind are in progress. Moreover, in case of the plane transmitting grating and plane mirror, as above shown, the same simplification is possible, if the lens is replaced by the telescope at T. But in this case the spectra are intersected by strong *stationary* interferences due to reflections from front and rear faces and consequently not conveniently available. A reflecting grating and telescope would not encounter this annoyance. In general, however, as in the disposition adopted fig. 1, *b*, the light enters opposite the observer and the light directly transmitted can be screened off; this is a practical convenience in favor of the transparent grating. The reflected spectra used may be placed at any level by rotating the mirror *m* on a horizontal axis.

On further repeating the work by the use of the concave mirror *m*, and a strong eyepiece at T, fig. 1, *b*, and using a compensator, I eventually succeeded in *erecting* the interference design, C, fig. 1, *a*. It then took the form given at D and this seems to furnish the final clue to the subject. In other words, the design consists of a new type of extremely eccentric ellipses, with their long axes parallel to the Fraunhofer lines, each end having the outline of a needle point, possibly even concave outward. Only one end of a closed curve is obtainable. These jet black lines dance on the highly colored background of less than half the width between the two sodium lines. The interference design, therefore, would be the same (apart from color) as that which would be obtained, if the spectrum containing ordinary elliptic interferences were to shrink longitudinally from red to violet, till it occupied less than half the space between the two D lines. In fact I have at other times obtained just such patterns, with all the colors present, *but not in the pure yellow*, as in the present case. Vertically, the path difference is always due to more or less obliquity of the rays passing through the plate of the grating. Horizontally, however, the equivalent path difference results, in the present case, from the fact that one wave-length of a pair has increased, whereas the other has diminished, while both may pass through the same thickness of glass and air.

4. *Case of coincident spectra with one reversed on a given longitudinal axis.*—For this experiment it is necessary to reflect the first order spectra issuing at the grating G, figure 2, *a*, from the ruled face *g* (a narrow preferable horizontal blade of

white light is here furnished by the collimator *L* with a *horizontal* slit and the rulings of the grating are also horizontal and parallel to it), twice in succession and preferably from mirrors *M* and *N* and *m* and *n*, reflecting normally to each other and inclined at an angle of roughly 45°. Each of the mirrors *M* and *N* must be revolvable about a horizontal axis parallel to the slit and furnished with three adjustment screws relatively to axes normal to each other, one of which is horizontal. The mirrors *m*, *n* are the silvered faces of a prism right-angled at the edge. It is moreover to be placed on the slide of a Fraunhofer micrometer so that the prism may be moved, gradually, up and down for the adjustment of distances.

On leaving the mirror *m*, *n*, the two spectra are carried by nearly horizontal and parallel sheets of divergent rays, which pass outward from the diagram. But it will be seen that one of the two spectra reaching the observer is reversed on the longitudinal axis relatively to the other; i. e. if one is in the position red $\left\{\begin{matrix}\text{Top}\\ \text{Bottom}\end{matrix}\right\}$ violet, $\begin{matrix}\text{the other}\\ \text{will be}\end{matrix}$ red $\left\{\begin{matrix}\text{Bottom}\\ \text{Top}\end{matrix}\right\}$ violet. The subsequent passage of the rays is shown in figure 3, *b*, which is the side elevation and therefore at right angles to the preceding figure. The rays from *m* and *n* impinge on a distant slightly concave mirror *K* (about 1·7 meters in focal distance) placed somewhat obliquely, so that when the rays come to a focus at *F* near the micrometer, they may just avoid it. The partially overlapping spectra at *F* are viewed by a strong eyepiece *E*. The observer at *E* can then control the Fraunhofer micrometer by which *m*, *n* is raised and lowered, and the three adjustment screws of *M*.

The adjustment consists in first roughly placing all parts in symmetry with sunlight, until the two spectra appear at *E*. The lens may be removed. There should be a bright narrow spectrum band on each side of and near the edge of the prism *m n*; for it is clear that after passing the lens *E*, corresponding rays from *M* and *N* must both enter the pupil of the eye to be seen together. To make the spectrum parallel, the mirror *m n* is rotated, as a whole, around a vertical axis. The three screws on the mirrors *M* and *N* then assist in completing the adjustment; the rotation around the horizontal axis brings the sodium lines in coincidence (both must be clearly seen and sharp and at an appreciable distance apart); that around the oblique axis gives rise to more or less overlapping, as required. The need of a sharp coincidence of the sodium lines is very essential in all these experiments.

After proper vertical position of *m n* has been found by slowly moving the micrometer screw up and down, the fringes appear. They are usually very fine lines, indicating distant centers of the ellipses to which they belong. The appearance is roughly suggested in figure 3. They pass from the type *a* through *b* (contraction toward the violet end was not noticed), into the type *c*, when mirrors *m n* move in a given direction. The center of the ellipses is in the vertical through the field of the adjustment *b*, in which case the lines pass from end to end of the spectrum as a narrow band near the longitudinal axis of actual coincidence of spectra, symmetrically.

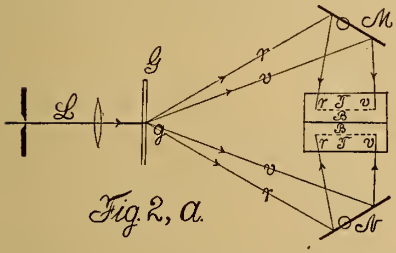


Fig. 2, a.

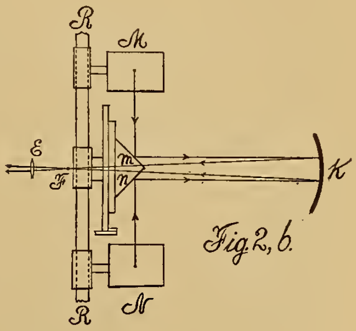
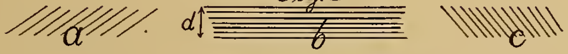


Fig. 2, b.

Fig. 3



The height or breadth of the longitudinal interference band, *d*, in fig. 3, is not greater than 1·5 to 2 times the distance apart of the sodium lines at right angles to the band. From this the angular divergence of the breadth of the band may be found, since $\lambda = D \sin \theta$, where λ is the wave-length of light, D the grating space and θ angle of diffraction. Hence for the two sodium lines $\Delta\theta = \Delta\lambda / D \cos \theta$. Since $D = 351 \times 10^{-6}$, $\cos \theta = \cdot 986$, and $\Delta\lambda = 6 \times 10^{-8}$,

$$\Delta\theta = 1 \cdot 7 \times 10^{-4} \text{ radians.}$$

Since the width of the band is about twice this, it will be 68 seconds of arc, or roughly about a minute in breadth. Within the strip, when the fringes are horizontal, I counted about five of them, so that their distance apart would be about 14 seconds of arc.

It appears, therefore, that rays of a given color, say of the wave-lengths at *D*, which leave the grating at a given point and at an angle of about one minute in the plane of the *D* line, are still in a condition to interfere; whereas strictly speaking only those rays which lie in the common longitudinal axis of rotation of the two coincident spectra symmetrical to this should be in this condition. Such interference should not apparently be appreciable, since the white rays are independent and come from two different points of the slit. If we consider the angular deviation of pencils of parallel rays crossing ths grating, to be equivalent to the divergence of their respective optical axes at the collimating lens (about 45 cm. in focal distance), the distance apart of two points of the slit the rays of which are still able to produce interference is $x = 45 \times \Delta\theta = 45 \times 1{\cdot}7 \times 10^{-4} = 7{\cdot}6 \times 10^{-3}$ cm. or nearly ·1 mm. Hence points of white light in the slit about ·1 mm. apart along its length produce the band of interferences in question, extending in colored light from red to violet.

5. *Interference of the corresponding first order spectra of the grating, in the absence of rotation.*—This apparatus seemed to be of special interest, since the rays used do not retrace their path and are thus available for experiments in which rays traveling in one direction only, are needed.* I have tried both the adjustments given in figure 4*a* and *b*. The latter, since the rays are more nearly normally reflected at the mirrors *M* and *N*, has some advantages; but the other succeeds nearly as well. The difficulty encountered is a curious one of adjustment, which was not anticipated. In other words, if the longitudinal axes of two identical spectra are in coincidence, the Fraunhofer lines are likely to be at a small angle to each other and complete interference is therefore impossible. Again if the spectrum lines are in coincidence, the longitudinal axes usually diverge by a small angle. Furthermore the interferences are almost always eccentric and the lines hairlike, indicating distant centers. I have not succeeded in making a perfect adjustment, systematically, but the discrepancies are themselves interesting in their bearing on the subject of this paper. In figure 4, *L* is a vertical blade of white light from a collimator with fine slit and *G* is the grating. The two first order spectra leaving the ruled face at the line *g* strike the opaque mirrors *M* and *N*, the former on a micrometer moving the mirror parallel to itself. From *M* and *N* the rays reach the half silvered plate of glass, *HS*, where one is transmitted and the other reflected into the telescope *T*. The coincident rays *R* are superfluous.

After placing the parts and roughly adjusting them for symmetry with sunlight, the finer adjustment may be undertaken. It may be noticed that the two systems *M* and *N*, and *G* as well as *HS*, can be used for further adjustment, separately. All are provided with adjustment screws relatively to rectan-

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* Cf. this Journal, xxxiv, pp. 101, 1912, on an air column carrying electrical current.

gular axes. To put the mirrors *M* and *N* in parallel and in the vertical plane with the grating *G*, the half silver plate should be removed and replaced by a small white vertical screen of cardboard, placed at right angles to the direction of *HS* in figure 4, and receiving both spectra. A fine wire is drawn across the slit to locate the longitudinal axis and an extra lens may be added to the collimator and properly spaced until the doublet insures sharp focusing. Both mirrors *M* and *N* are

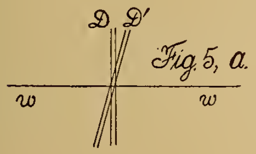

Fig. 5, a.

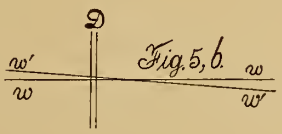

Fig. 5, b.

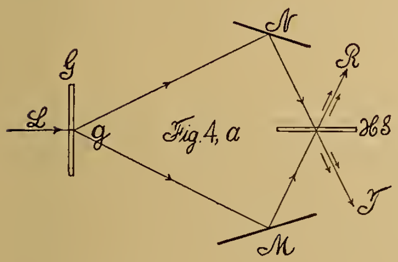

Fig. 4, a

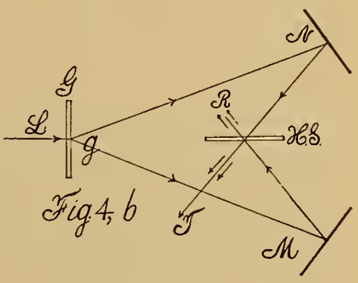

Fig. 4, b

now rotated on horizontal axes, until the longitudinal black lines in their spectra cease to diverge and coincide accurately. *G*, *M*, *N* may now be considered in adjustment. On returning the half silvered plate, *HS*, it in turn is to be carefully rotated around horizontal and vertical axes, until the horizontal black line in the spectrum and the sodium line (always incidentally present in the arc lamp) both coincide. But as a rule it will be found that if the longitudinal axes *ww*, figure 5*a*, coincide, the *D* lines cross each other at a small angle, exaggerated in the figure. The interferences, when found by moving the micrometer at *M*, are usually coarse irregular lines, indicating a center not very distant and located on the level of a band where the *D* lines cross.

On the other hand, if the *D* lines are brought to coincidence by moving the adjustment screws on *M* and *N* (which throws them out of parallel), the longitudinal axes *ww*, *w′w′*, figure 5*b*, diverge at a small angle and the interferences are found in a vertical band where the lines *ww* and *w′w′* cross. This band is relatively wide however as compared with the cases in paragraphs 2 and 3. Nevertheless I have looked upon these results as additional proof of the possibility of interference. For in neither case ought they to occur if the spectra are not quite coincident horizontally and vertically. If they do occur, it would seem that a certain small latitude of wave length adjustment is permitted even with light waves.

The cause of this lack of simultaneous parallelism I was at first inclined to refer to the grating itself, as it occurred with an Ames grating ruled on glass, with a Michelson reflecting grating and with a film grating, in about the same measure. But subsequently, on adopting the method of figure 4, *b*, the divergence was largely removed and the interferences were now visible throughout the whole of the spectrum. The discrepancy is probably due to insufficient normality of the plate of the grating to the incident white ray, since one of the rays is twice reflected. In any case the adjustment of the coincident sodium lines must be very accurate if the fringes are to be sharp; certainly as little as half their distance apart will obscure the phenomenon.

Though the spectra are bright the interferences are not as good as with the usual method (paragraph 1); i. e. the dark lines are not black. Neither have I found an available or systematic method for centering the fringes, so that the lines obtained are usually delicate. Again the position of the collimator, both as regards slit and lens, is here of very serious importance. Any micrometric horizontal motion of either in its own plane will throw the fringes out. Finally the whole spectrum travels with the motion of the micrometer mirror *M*. The apparatus is thus too difficult to adjust for use, to be of practical interest when simpler methods are at hand. The effect of tremors acting prejudicially on so many parts is exaggerated.

6. *Conclusion.* The phenomena of paragraphs 2, 3 and 4, showing definite and characteristic interference in case of two coincident spectra, crossed either on a longitudinal or transverse axis, represent the chief import of the present paper. These results cannot be due to the diffraction of a slit (regarding the line of coincidence as such), owing to their relatively small magnitudes and their independence of the breadth of the slit. Since there is in each case but a single line of points or axis, the disturbance of which comes from identical sources, we might regard the image of this line in the telescope to be modified by the diffraction of its objective. But if the interferences originated in this way, the Fraunhofer lines of the spectrum should show similar characteristics and the diffraction pattern should differ from those observed. Thus the conclusion is apparently justified that distinct and independent points of the narrow slit whose distance apart on its length is not

greater than ·1 mm., are still capable of producing interference in each of the colors of the spectrum (longitudinal axes coinciding). This phenomenon is virtually one of homogenous light, the same type of interference occurring in each color from red to violet. They belong moreover to the elliptic category, being of the same nature as those used in displacement interferometry. With the exception of the points lying on the longitudinal axis of rotation or of coincidence, all the pairs of points of the two coincident spectra owe their light to different sources; i. e. they are not color edimages of one and the same point in the slit.

Again, in case of rotation of one of the coincident spectra around a transverse axis (Fraunhofer line), colors which differ in wave length by less than half the distance apart of the two sodium lines also admit of interference. This permissible difference of wave length is thus relatively about

$$\frac{\Delta\lambda}{\lambda} = \frac{\cdot 5 \times 6 \times 10^{-8}}{59 \times 10^{-6}} = 5 \times 10^{-4}$$

or less than ·1 per cent. The character of these interferences is distinctive. They are not of the regular elliptic type, but usually arise and vanish in a succession of nearly vertical (parallel to slit), regularly broken lines. Later observations however, revealed as their true form a succession of long, spindles or needle-shaped designs. The chief peculiarity is observed in their almost scintillating mobility, which in the above text has been referred to the inevitable tremors of the laboratory. It is, however, interesting to inquire into the conditions of the possibility of observable beating light waves. For two waves very close together of frequency n and n' and wave lengths λ and λ', if V is the velocity of light, the number of beats per second would be

$$n' - n = \mathrm{V}\,(1/\lambda' - 1/\lambda) = V\Delta\lambda/\lambda^2, \text{ nearly.}$$

Therefore in case of the two sodium lines for instance,

$$n' - n = 3 \times 10^{10} \times 6 \times 10^{-8}/3500 \times 10^{-12} = 5 \times 10^{11}$$

i. e. about 5×10^{10} beats per ·1 second, the interval of flickering. Naturally this seems to be out of all question: yet one is confronting a source which is an approach to a mathematical line; and though I am not apt to stretch a rather conservative imagination quite so far, I should like to see this interference produced under absolutely quiet surroundings. Its appearance is altogether singular and not like the case of paragraph 4, where there is also perceptible tremor, or with the general case of trembling interference patches, with which I am, unfortunately, all too familiar.

In this place, however, it is my sole purpose to present, at its face value, an observation which is spacial, independent of time consideration, and the laterally cramped character of the new interference, with its long hair-like lines thrust into a strip less than half the distance apart of the sodium lines, is the only evidence submitted. For, if the coincident path of two rays of slightly different wave-lengths λ and λ' which interfere, is x, then there are x/λ and x/λ' complete waves in the given path; and in case of original identity in phase, reinforcement will occur when

$$x(1/\lambda - 1/\lambda') = 1, 2, 3, \ldots n.$$

In other words at the nth reinforcement

$$\Delta\lambda = n\lambda^2/x.$$

Hence since λ^2 is very small and x relatively very large, the exceedingly small value $\Delta\lambda$ (i. e. the very narrow strip of spectrum within which the phenomenon occurs) is apparent. In the above experiments the estimates, in round numbers, were $\Delta\lambda = 2{\cdot}4 \times 10^{-8}$, $\lambda^2 = 36 \times 10^{-10}$. Hence if $n = 1, x = {\cdot}15$ cm. so that one reinforcement occurs about at each 1·5 millimeter along the rays.

It remains to be investigated why these nominally beating wave trains with an infinitesimal group period, can be recognized at all. But into this question I am not now prepared to enter, as the answer is almost wholly dependent on experiments in progress. If whatever vibrates has inertia (electric displacement), the case of *forced vibrations* is suggested (approximate resonance), with opposite phases on the two sides of the transverse line of coincidence, essential.

The characteristic feature of the new phenomenon is this, that apart from intensity, it *persists without variation, through a path difference of over 10 millimeters*, i. e. through 15,000 or 20,000 wave lengths. It follows, since the paths, grating-mirror-grating, are alone significant, that two individual light waves of the same ray over 15,000 wave lengths apart are still appreciably identical. Beyond that the waves no longer correspond in orientation and cannot interfere in a way to produce alternations of accentuated brightness and darkness. Again, these 5 millimeter lengths may actually be discontinuous and represent successive discharges of radiation (each lasting about $1{\cdot}5 \times 10^{-11}$ seconds), separated by absence of light motion along the ray.

Through the years, I seem still to hear the lament of my old friend and teacher, Ogden N. Rood, of the time he had wasted looking for the interference of differentiated light waves. If with more modern facilities I have reached a conclusion, it would be a privilege to associate it with his memory.

Brown University, Providence, R. I.

Art. XXXVII.—*The Brandywine Formation of the Middle Atlantic Coastal Plain;* by William Bullock Clark.

Name.—The name Brandywine* is proposed for this formation as the deposits are extensively and typically developed in the vicinity of Brandywine, Prince George's County, Maryland.

Synonymy.—(*a*) Appomattox formation.—The name Appomattox was proposed by McGee† in 1888 for the older terrace accumulations and various other deposits exposed in the valley of the Appomattox River in Virginia. The same author‡ in 1890 discussed their southern extension and Darton§ in 1891 described the northern extension of the deposits into Maryland and adjacent areas.

The term Appomattox was used by both McGee and Darton to designate two or more clearly recognizable stratigraphic units separated by well defined escarpments. In McGee's description of the Appomattox formation he included the two higher terrace formations described by Shattuck as Lafayette and Sunderland and also extended the formation down the valley lines to embrace even later Pleistocene deposits including parts of the Wicomico and Talbot formations, as well as weathered portions of the Aquia formation of the Eocene.

(*b*) *The Lafayette Formation.*—The name Lafayette was applied by McGee‖ in 1891 to the deposits of the Middle Atlantic Slope which he had previously described under the name Appomattox formation on the assumption that they belonged to the same formation as those so designated by Hilgard¶ in Lafayette County, Mississippi. Hilgard's type area was shown to be of Wilcox Eocene age by Berry** and the work of Vaughan, Stephenson, Shaw, and others has

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* The recognition by the U. S. Geological Survey and the various State Surveys in the Atlantic border area of the inappropriateness of the term Lafayette as employed in the Atlantic border region has led to the proposal by the author of the name Brandywine for the oldest of the terrace formations of that district. This name has already been submitted to the Board of Geologic Names of the U. S. Geological Survey and adopted by it.

† McGee, W. J.: Three Formations of the Middle Atlantic Slope, this Journal, xxxv, 328–330, 1888.

‡ Idem: Southern Extension of the Appomattox Formation, ibid., xl, 15–41, 1890.

§ Darton, N. H.: The Mesozoic and Cenozoic Formations of Eastern Virginia and Maryland, Bull. Geol. Soc. Amer., ii, 445–447, 1891.

‖ McGee, W. J.: The Lafayette Formation, 12th Ann. Rept. U. S. Geol. Survey, 347–521, 1891.

¶ Hilgard, E. W.: Orange sand, Lagrange and Appomattox, Amer. Geol., viii, 139–131, 1891.

** Berry, E. W.: The age of the Type Exposures of the Lafayette Formation, Jour. Geol., xix, 219–256, 1911.

demonstrated that the Lafayette as defined by Hilgard and described in detail by McGee comprised the weathered surface materials of various Cretaceous and Tertiary formations. Shattuck* in his study of the surficial formations of Maryland limited the term Lafayette to the highest of the terrace formations, the formation to which the author now gives the name of Brandywine.

The terms Appomattox and Lafayette as originally employed in the Middle Atlantic Coastal Plain embraced much more, therefore, than it is proposed to include under the name Brandywine formation, and likewise, the diagnosis of that formation is based on different physiographic conceptions from those used by McGee and Darton. Furthermore, the term Lafayette as originally employed in Mississippi was based on a misconception of the stratigraphy of the region. The use, therefore, of either the term Appomattox or Lafayette for any formational unit is impracticable.

Areal outline.—The Brandywine formation covers an extensive area in the southern Maryland peninsula, reaching from the eastern boundary of the District of Columbia to the northern line of St. Mary's County with numerous outliers both to the north and to the south of these lines. It attains a maximum width, therefore, from northwest to southeast of nearly 40 miles. From this region it narrows both to the northeastward and to the southwestward, being confined largely to the landward margin of the Coastal Plain. It reaches to the northward through the central counties of Maryland into Delaware and Pennsylvania, while to the southward it has been traced in the interstream areas and along the landward border of the Coastal Plain through Virginia into the Carolinas. Less is known of the details of its areal distribution in Virginia than in Maryland and the states which lie to the north of it.

Altitude and character of landward boundary.—The altitude of the landward boundary reaches 400 feet in the outliers in the western part of the District of Columbia, 486 feet at Burtonville in Montgomery County, 508 feet at Catonsville, Baltimore County, 480 feet at Loch Raven, Baltimore County, and 470 feet at Woodlawn, Cecil County. No one of these more western outliers covers more than a few square miles of area. Each is extensively eroded and isolated from the main body of the formation farther seaward. All are found in interstream positions, their coarse gravel content protecting them from destruction.

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*Shattuck, G. B.: Pliocene and Pleistocene, Maryland Geol. Survey, 291 pp., 75 pls., 10 figs., 1906.

Altitude and character of seaward boundary.—The altitude of the formation along the seaward boundary in northern St. Mary's County is not over 200 feet while farther northward in Maryland, due to the more extensive later Pleistocene encroachments of the sea in those areas resulting in the removal of the deposits along the seaward face, elevations of 240 feet are found at Marriott Hill, Anne Arundel County, and 300 feet on Elk Neck, Cecil County. Clearly defined escarpments appear in many places along the seaward margin although at other points such escarpments are wanting, the higher terrace presenting a long featureless slope along its front which gradually coalesces with the next terrace level. A significant feature is found near Charlotte Hall in St. Mary's County where a seaward-facing escarpment extends entirely across the divide of the peninsula of southern Maryland and separates the Brandywine from the lower terrace level of the Sunderland. The Sunderland plain also passes at this point between two of the outliers of the Brandywine and over the divide between two small streams rising within the area.

Rate and direction of slope of surface.—The slope of the Brandywine surface within the main area of outcrop in the peninsula between the Potomac and Patuxent rivers is somewhat over five feet to the mile, although it is greater nearer the landward margin than seaward. In the former case the slope reaches 15 feet or more to the mile in the vicinity of the District of Columbia, a feature also shown to the northward in Baltimore and Cecil counties, Maryland, while nearer the seaward margin it declines to about three feet to the mile in southern Prince George's and northern St. Mary's counties.

The direction of slope is from northwest to southeast at right angles to the coast lines of the period.

Amount of dissection.—The Brandywine formation is extensively dissected, the largest continuous area of outcrop being found in the interstream area between the Potomac and Patuxent rivers. Here the margin of the formation has been extensively dissected, resulting in many outliers. In Prince George's and Charles counties, Maryland, however, are undissected and undrained tracts possessing the essential features of the old terrace surface and appearing today as broad and nearly featureless plains. This is best seen in the area extending from Cheltenham, Prince George's County, southward to Hughesville and Waldorf and somewhat beyond, into Charles County, Maryland.

Component materials and structure of deposits.—The Brandywine formation is composed of gravel, sand, and loam. Over considerable areas the gravel is found occurring in greater abundance at the base, while sand and loam more especially characterize the upper portions of the formation. The beds or lenses are irregular and often the materials are mixed together in a confused manner. Cross-bedding occurs in the sands and gravels but in general the materials are imperfectly sorted and are found intermingled in varying proportions, the gravel and sand frequently containing much clay.

The gravels are chiefly developed in the landward portions of the formation and decline in frequency as well as in size of cobbles toward the seaward portions of the formation and are almost entirely absent near the seaward margin, being replaced altogether by sands and loams. The materials are of varying sizes and shapes, generally more or less angular with rounded edges and rarely affording the discoidal pebbles characteristic of sea beaches. The pebbles toward the landward portion of the formation are almost invariably covered with a dark-brown, ferruginous coating, but farther seaward the amount of iron decreases and the coating of iron oxide is practically absent. The pebbles are largely of quartz but some are of crystalline and other rocks and a few even of Newark sandstone, which shows that they were derived from the Piedmont and Appalachian regions. Many were doubtless redeposited from the early Cretaceous formations. Scattered among the cobbles and pebbles and also at times among the sands and loams are angular bowlders of Piedmont or Appalachian origin. The gravels especially in the landward portions of the formation are often much decayed, the pebbles readily breaking down under light blows from the hammer.

The sands are both coarse and fine and doubtless have largely the same origin as the gravels although more largely derived from the older Coastal Plain formations. This is doubtless especially true of the seaward portions of the formation, which were evidently derived in considerable measure from the sandy beds of the older Miocene formations, which must have extended widely over the eastern margin of the Piedmont and are today recognized in outliers some distance to the west of the Coastal Plain border. At the same time the sandy members of the underlying Eocene and Cretaceous formations must also have contributed their quota. The sands are much more heterogeneous in the landward portions of the formations than in the seaward and are frequently very compact when cemented by iron oxide or when they contain an admixture of clay, loamy sands or sandy loams being frequently found, particularly in the landward portions of the formation. Beds of pure quartz sand are infrequent and when present are not of great thickness or wide extent. They increase in prominence, however, seaward.

The loams are widely extended but of very variable sorts.

They are more largely found at the top than lower in the formation but may occur at all levels. They are frequently intermingled with the sands and gravels, forming sandy and gravelly loams, often making a matrix for cobbles of considerable size. The loam capping of the formation, which occurs widely, varies from a few inches to 10 feet or more in thickness. In the landward portions of the formation the loam contains considerable iron and at times has a decided orange color. In some areas, particularly in northern Charles County, it has a pronounced mottling of drab and brick-red which is particularly noticeable when the material is wet. The loams in the seaward portions of the formation are generally grayish-yellow in color. Although often mixed with gravel and sand the loams are in places very argillaceous and fine in texture, especially in the upper portions of the formation. They have at times irregular beds of coarse sands or even gravel interstratified with them, thin seams of gravel not being an uncommon feature. The loams are frequently very hard and compact, especially when rich in hydroxide of iron. Both the sands and the loams, particularly the gravelly or sandy loams, show a marked case-hardening on exposure to the weather.

The Brandywine formation has a thickness of from 10 to 30 feet, the thickness for the most part increasing from the landward toward the seaward margin of the formation, although there are many exceptions to this rule where the deposits have been laid down in the inequalities of the surface of pre-Brandywine time. Exceptional thicknesses of over 50 feet have been found. In general the coarser materials toward the landward margin have a thickness of from 5 to 15 feet while in the seaward portion of the formation the finer sands and loams reach from 20 to 30 feet.

No determinable fossils have been recognized in the type area although Darton refers to the presence of a few indeterminable molluscan shells in Virginia which may well be reworked Miocene forms.

The soils most widely distributed on the Brandywine formation have been described by the United States Bureau of Soils as the Leonardtown loam, the Windsor sand, and the Norfolk sand. The Leonardtown loam is generally found where the upper layers of the Brandywine formation are loamy and consist of a yellow silty loam having an average depth of about 10 inches. It is underlain by a heavier yellow loam which usually grades into a mottled loam at a depth of from 28 to 32 inches. More or less sand and gravel generally appear in the subsoil. Along the borders of this soil type the sand and gravel become more prominent as the soil becomes thinner and the Leonardtown loam grades over into more stony and gravelly types. The Windsor sands, the next most important soil type found in the Brandywine formation, consists of a medium to coarse sandy soil that generally contains about 10 per cent of fine gravel. The soil is loose and friable and reaches to a depth of about 8 or 10 inches and is underlain by a coarse sandy subsoil. It is quite widely extended but is most common in the area midway between the landward and seaward borders. The Norfolk sand is less widely extended in the Brandywine formation than the two preceding soils and consists of a medium to coarse orange or yellow sand to a depth of about 10 inches and is underlain by a coarse sandy subsoil which usually becomes loamy at a depth of about 3 feet.

Vegetation and culture.—Extensive areas are covered with scrub pine and culled hardwoods of various types, the scrub pine being found largely growing on the Windsor sand. Large areas, however, are under cultivation. The Leonardtown loam, because it is capable of retaining a considerable amount of moisture during the entire growing season, is well adapted to growing grass, wheat, and corn where general farming is practised, and to cabbages, cucumbers, and late strawberries in the trucking areas. It is only producing, however, to its full capacity in the northern part of the county, where the soil has been extensively enriched and where a ready market for its products has been found in Washington. The Windsor sand is very porous but is well adapted to early truck crops, early peaches, and under certain conditions to fine grades of tobacco. Its loose, porous character makes it particularly hard to manage during a protracted drought and for this reason intensive cultivation is required including the incorporation of considerable amounts of organic material. The Norfolk sand, although very porous, has been utilized in general farming and truck growing and is well adapted for early strawberries, melons, sweet potatoes, and small crops of high grade tobacco.

Stratigraphic relations of the deposits.—The Brandywine formation overlies all of the older Coastal Plain formations of Tertiary and Cretaceous age unconformably and at a few points rests on the crystalline rocks of the Piedmont. It is separated from the next younger or Sunderland formation throughout much of the region by a clearly marked escarpment, the Sunderland formation wrapping at a lower elevation about the lower margin of the formation unconformably and filling the pre-Sunderland valleys.

One of the most striking physiographic features of the region is the Sunderland plain extending into the pre-Sunderland valleys and abutting against their irregular slopes. Streams are often absent today in these old valley lines but where present have cut irregular channels through the surface of the Sunderland terrace. Where the streams have eroded the Sunderland, as well as at many points along the landward extension of the Brandywine formation where the interval between the terrace levels increases, the underlying formations appear in outcrop beneath the Brandywine.

Local Brandywine area.—Brandywine, Prince George's County, Maryland, is located on the slightly-eroded surface of the old Brandywine terrace not far from the center of the largest tract still preserved intact. The surface materials in this region consist of sandy loams, while the deeper trenches cut by the streams around the margin of the tract show irregular beds of coarse sand and gravel, the latter generally small in size. The formation attains its maximum thickness in the general area in which Brandywine is situated. No section of the formation is exposed at Brandywine since it is situated on the uneroded surface of the formation, but the adjacent ravines both to the east and west cut through the formation, exhibiting the gravels, sands, and loams characteristic of the formation.

Interpretation of history.—The Brandywine epoch was opened by a depression of the continent border which carried the waters of Brandywine time over the eroded Tertiary and Cretaceous deposits to well within the Piedmont area. A small outlier of questionable origin but containing gravels similar to those of the Brandywine formation is found far within the Piedmont in the Frederick valley, at an elevation which corresponds with the possible transgression of the sea into the broader valleys of the Piedmont district. At all events, the tilting of the coastal area must have brought about renewed erosion of the adjacent land with the result that extensive and more or less heterogeneous accumulations of gravels, sands, and clays were deposited rapidly along the margin of the Brandywine sea, or more widely scattered without much sorting by the currents and undertow of the period. Many of the deposits, especially the coarser types, point to a fluviatile origin of the materials, and many of the beds show in their irregular and confused stratigraphy, characters such as occur from a combination of fluviatile and flood-plain deposition. At the same time commingled with these probable fluviatile elements are other materials of distinctly marine or estuarine origin, and it, therefore, seems probable that a combination of fluviatile and off-shore agencies must be predicted for the formation of the Brandywine deposits. Furthermore, the broad terrace plain, formed of materials of no great thickness, which gradually thicken seaward as so often occurs in near-shore marine beds, point to the existence of a large body of water into which the ill-sorted materials of the time were rapidly carried. Although fluviatile deposition may have actually taken place over part of the area during the period of subsidence it must have been replaced ultimately by off-shore deposition as the sea transgressed. In no other way can the form and structure of the formation be fully interpreted.

Age of the formation.—There has been much discussion of the age of the deposits composing the Brandywine formation. but as no determinable fossils have hitherto been found in the beds no definite conclusions have been reached. It has been generally accepted that the post-Brandywine deposits are of Pleistocene age, while the Brandywine formation itself has been questionably referred by most authors to the Pliocene on the ground of the more extensive erosion to which the strata have been subjected and the greater decay of the constituent materials. The author raises the question, however, whether the Brandywine formation might not with entire propriety be referred to the early Pleistocene, all of the surficial terrace deposits therefore of the Middle Atlantic Coastal Plain being placed in that event within the limits of the Pleistocene.

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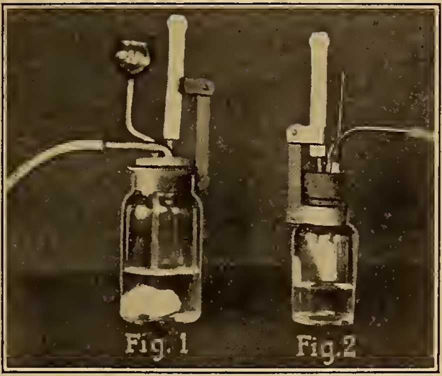
ART. XXXVIII.—*On Two Burners for the Demonstration and Study of Flame Spectra*; by PHILIP E. BROWNING.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—cclxxiii.]

IN the demonstration and study of flame spectra it is obviously advantageous to impart the colors to the flames for a longer period of time than can be secured by simply inserting in the flame a platinum wire or asbestos fiber previously dipped into a solution of a compound of the element whose spectrum is desired.

The purpose of this paper is to describe two forms of apparatus which have been found convenient for securing a certain degree of permanence to the colors in the flame.

Fig. 1 shows a burner constructed as follows: An ordinary salt mouthed bottle is fitted with a three-holed stopper. Through one of these holes a tube is placed which connects by means of a rubber tube with the gas supply. Through the second a tube drawn out to a jet is inserted and over this jet a porcelain tube is suspended in such a way as to make a colorless flame possible. These porcelain tubes are such as are used often as insulators in electric wiring. They are preferable to glass or metal because they impart no color to the flame and do not corrode. Through the third opening in the stopper an ordinary thistle tube is inserted.



To operate the burner a piece of marble or a carbonate mineral of strontium or barium, for example, is placed in the bottle with enough water so that when the stopper is placed in position the end of the thistle tube is submerged in the water.

The gas is then turned on and the burner so adjusted as to give a good colorless flame. Enough acid is then added through the thistle tube to start a gentle evolution of carbon dioxide, and this gas carries enough of the solution to be swept by the current of gas into the flame. Mineral carbonates have an advantage over commercial precipitated carbonates on account of their freedom from sodium. This form of apparatus may be used to obtain sodium, potassium and lithium flames, but the apparatus designated in fig. 2 is rather better for these elements.

Fig. 2 is modelled after a type of burner used in the laboratory of M. Urbain at the Sorbonne in Paris, where the author made its acquaintance. This apparatus is constructed similarly to that marked fig. 1 except that in place of the thistle tube a tube is so arranged that a glass rod attached by a rubber connector may slide up and down within it. Attached to the end of the glass rod by a hook made by drawing out the glass is a piece of zinc bent in shape of a tube about an inch in diameter. The form here described differs from the Paris type in the substitution of a porcelain tube for a glass tube, not essential if the burner is used only for sodium, and the tube-shaped piece of zinc rather than a strip of zinc to secure a greater surface of metal.

To operate this burner a solution of a sodium, potassium or lithium salt is placed in the bottle and enough acid is added to give a gentle evolution of hydrogen with the zinc. The stopper is placed in position and the zinc lowered into the liquid by means of the glass rod. The current of hydrogen operates to bring the solution of the salt into the flame.

ART. XXXIX.—*On the Preparation of Glycocoll and Diethyl Carbonate;* by W. A. DRUSHEL and D. R. KNAPP.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—cclxxiv.]

THE preparation of glycocoll by the interaction of ammonia and chloracetic acid is attended by by-reactions which make it impossible to obtain a quantitative yield of the amino acid. In 1858 Perkin and Duppa* obtained a small yield of glycocoll by the action of ammonia upon bromacetic acid at the boiling temperature; later Cahours,† repeating the experiment with chloracetic acid, got a yield of 10 per cent to 15 per cent. Mauthner and Suida‡ improved the yield by working with ammonia and chloracetic acid in the cold, and more recently Kraut was able to get a yield of 50 per cent to 55 per cent by cooling the reaction mixture to 10°. The very marked improvement in yield obtained by Kraut suggested the possibility of even a better yield by working at 0° and keeping the reaction mixture saturated with ammonia until all of the chlorine was fixed as ammonium chloride.

In this investigation 700$^{cm^3}$ to 800$^{cm^3}$ of ammonia water were cooled to 0° in an ice bath, and saturated at this temperature with gaseous ammonia. One hundred grams of chloracetic acid were dissolved in the least possible amount of water and slowly run into the ice cold saturated solution of ammonium hydroxide, keeping the reaction mixture at 0° and saturated by passing gaseous ammonia. In our earlier experiments the mixture was kept at 0° for about fifteen hours and was then allowed to stand at room temperature for several days. In the later experiments the temperature was kept at 0° for more than four days; the reaction was found to go to completion at this temperature in about five days. The velocity of the transformation of the chloracetic acid was determined by pipetting off 5$^{cm^3}$ portions of the reaction mixture from time to time, neutralizing the excess of ammonia with ice cold nitric acid and titrating the ammonium chloride present with standard silver nitrate, using potassium chromate as an indicator. A good concordance in velocity constants was obtained by making the calculation from the usual formula for second order reactions. The mean of a series of five velocity constants is 0·000223. The glycocoll was recovered from the reaction mixture and purified by the copper hydroxide method; the use of copper carbonate instead of copper hydroxide suggested

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* Quart. Jour. Chem. Soc., xi, 22.
† Compt. rend., xlvi, 1044; cvii, 147.
‡ Monatsh., xi, 374.
§ Ann. Chem. Pharm., cclxvi, 299.

by Clarke* was also tried but was found to be much less satisfactory than copper hydroxide. In no case did the yield of pure glycocoll exceed 55 per cent of the chloracetic acid used. It does not seem possible to increase the yield of glycocoll by changing the conditions of Kraut's method in the direction of lowering the temperature or increasing the concentration of ammonia during the reaction.

Diethyl Carbonate.—Since cyanformic ester is readily converted into aminoacetic ester by reduction, it seemed desirable to examine the methods of preparing cyanformic ester. In 1895 Nef† obtained this ester mixed with some diethyl carbonate by the action of potassium cyanide upon chlorformic ester in 25 per cent aqueous alcohol at −13°, allowing the temperature to rise slowly during the course of the reaction to −2°. Under these conditions only about 50 per cent of the chlorformic ester was converted into cyanformic ester. In our experiments absolute alcohol was used, resulting in the abundant formation of diethyl carbonate without any cyanformic ester. Powdered potassium cyanide was covered in a flask with absolute alcohol and then one equivalent of chlorformic ester mixed with an equal volume of absolute alcohol was slowly added in small portions through a reflux condenser under a good draught hood. Heat was evolved, hydrocyanic acid was given off and the reaction mixture became red in color. The mixture was finally boiled for an hour on the water bath to bring the reaction to completion. The residue was then filtered off and the filtrate was fractionally distilled. The first fractionation gave almost pure diethyl carbonate, probably according to the equation $C_2H_5CO_2Cl + KCN + C_2H_5OH = (C_2H_5)_2CO_3 + HCN + KCl$. After redistillation the product boiled at 127°, and its identity as diethyl carbonate was further established by determining its molecular weight; by determining its saponification equivalent as 59, its specific gravity as 0·968 at 25°; and finally by preparing urethane from the product by the action of ammonia.

No cyanformic ester could be isolated from the reaction mixture and the yield of diethyl carbonate after purification was 50 per cent of the chlorformic ester used.

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* H. T. Clarke, Org. Chem., p. 290.

† Ann. Chem. Pharm., cclxxxvii, 308.

Art. XL.—*On the Preparation and Properties of Hydracrylic Esters;* by W. A. Drushel and W. H. T. Holden.

(Contributions from the Kent Chemical Laboratory of Yale Univ.—cclxxv.)

The esters of hydracrylic acid have up to the present time received but little attention, only the methyl and ethyl esters are mentioned in the chemical literature. The direct esterification of hydracrylic acid had apparently not been attempted until one of us * prepared ethyl hydracrylate in this laboratory by the direct esterification process. As described in the literature the indirect methods of preparation are objectionable since the esters are obtained in impure condition, containing impurities not easily removable. Obviously mineral acids can not be used as catalytic agents in the esterification of hydracrylic acid since under the necessary conditions hydracrylic acid is converted into acrylic acid and the resulting esters are chiefly acrylic esters.

The object of this investigation was to study the direct esterification of hydracrylic acid with the common alcohols, and the properties of the series of esters prepared in this way. Sodium hydracrylate was prepared from glycerine by the methods fully described in our previous paper.† The importance of keeping the solution of sodium hydracrylate slightly acid during evaporation is to be emphasized, since in alkaline solution condensation products are formed and only very little sodium hydracrylate is obtained. The best procedure appears to be nearly to neutralize β-iodopropionic acid with sodium carbonate, taking care to leave the solution distinctly acid. The solution is then treated with an excess of silver oxide freshly prepared and free from alkali. In this way the resulting solution contains sodium hydracrylate with a little silver hydracrylate. After filtering off the silver iodide the solution is treated with hydrogen sulphide to decompose any silver salt present. The silver sulphide is then filtered off and the filtrate is usually sufficiently acid to permit evaporation to dryness on the steam bath without the formation of more than very small amounts of by-products. The dry sodium hydracrylate thus prepared is further purified by recrystallization from 95 per cent alcohol. The yield is almost quantitative. Weighed portions of the purified and dried sodium hydracrylate were dissolved in the least possible amount of cold water and treated with a little less than the theoretical amount of 1:1 sulphuric acid, keeping the reaction mixture cold during the process. The water in the resulting mixture was evaporated off on the steam bath attended by only a slight loss of hydracrylic acid, leaving a residue of sodium sulphate and pure hydracrylic acid.

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* This Journal, xxxix, 113–121, 1915.

† Loc. cit.

The hydracrylic acid thus prepared, in about 50 gram portions, was extracted from the residue by the absolute alcohol to be used in the subsequent esterification process.

The alcoholic solution of hydracrylic acid, about 200^{cm^3} in volume, was treated with somewhat more than the theoretical amount of anhydrous copper sulphate free from sulphur trioxide. The reaction mixture was gently boiled with a reflux condenser on a sand bath until 80 per cent to 90 per cent of the hydracrylic acid had been esterified. The course of the esterification was followed by titrating from time to time 1^{cm^3} of the reaction mixture with decinormal barium hydroxide. After the completion of the reaction the copper sulphate was filtered off, the unesterified hydracrylic acid almost neutralized with anhydrous sodium carbonate, the excess of alcohol distilled off in a water or oil bath and the residue of hydracrylic ester subjected to fractional distillation under diminished pressure, usually at 12^{mm} to 20^{mm}. The esters which were prepared in this way and whose properties were then studied are the methyl, ethyl, propyl, isopropyl, isobutyl and isoamyl esters of hydracrylic acid. The densities of these esters were determined at 0° and at 25°; the values obtained are recorded in Table I.

TABLE I.

	0°	25°
Methyl hydracrylate	1·140	1·118
Ethyl "	1·085	1·064
Propyl "	1·052	1·043
Isopropyl "	1·071	1·058
Isobutyl "	1·013	1·003
Isoamyl "	0·988	0·976

These density determinations are referred to water at 4° and were made by means of a pycnometer * of a type which was especially devised for use in the qualitative organic analysis work in this laboratory. It consists of a capillary stem about 7^{cm} in length, a bulb to contain approximately 1^{cm^3} and a drawn out capillary about 1^{cm} in length. The capillary stem is graduated so that the pycnometer shall contain exactly one cubic centimeter of water at 4°. This type of instrument has the advantage that by a single weighing it gives fairly accurate specific gravity data even in the hands of those not skilled in the use of the more complicated types.

All of the hydracrylic esters investigated boil with decomposition at atmospheric pressure. Their boiling points were therefore determined directly over a range of pressures of 15^{mm} to about 100^{mm} and from the data obtained the boiling points

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* A cut of this type is published in the Journal of Industrial and Engineering Chemistry, vii, 187.

for atmospheric pressure were estimated by the graphic method. The results are recorded in Table II.

TABLE II.

Boiling points of hydracrylic esters.

Methyl ester		Ethyl ester		Isopropyl ester		Propyl ester		Isobutyl ester		Isoamyl ester	
B.P.	Press. in mm.	B.P.	Press. in mm.	B.P.	Press. in mm.	B.P.	Press. in mm.	B.P.	Press. in mm.	B.P.	Press. in mm.
79	12	84	12	95	12	98	12	104	15	121·5	17
87	20	91·5	19	99	20	102	19	112	20	124	20
107·5	40	95·5	22	109	35	120	43	126	45	137	36
111	56	116	62	114	42	127	62	129	50	147	58
121	94	127	102	128·5	82	142	107	143	88	159	95
184**	760	190**	760	196**	760	205**	760	212**	760	225**	760

** Calculated.

All of the esters of this series below the isobutyl ester are freely soluble in water in all proportions, but the higher homologues are not. The isobutyl ester is soluble in 18 parts of water and the isoamyl ester in 60 parts of water at room temperature.

The refractive indices of the esters were determined by means of the Pulfrich refractometer for the D line of sodium light and the following results obtained :

TABLE III.

	n	$(n-1)\cdot\frac{M}{d}$	M
Methyl hydracrylate	1·4306	40·10	104·0
Ethyl “ “	1·4271	47·30	118·0
Propyl “ “	1·4341	54·85	132·0
Isopropyl “ “	1·4303	53·68	132·0
Isobutyl “ “	1·4342	63·70	146·0
Isoamyl “ “	1·4374	71·65	160·0

These indices of refraction were determined at 23° C.

Conclusions :—

1. Hydracrylic acid is obtained from glycerine in a fair yield by slight modifications of the methods described in the literature.

2. Removal of the iodine from sodium β-iodopropionate rather than from the free acid by means of silver oxide has the advantage that the reaction goes at room temperature and requires only about half of the silver oxide theoretically required when the free acid is used instead of the sodium salt. Precautions must, however, be taken to prevent the solution from becoming alkaline. This is important since on evaporat-

ing an alkaline solution of sodium hydracrylate condensation products are formed and but very little sodium hydracrylate is found in the residue.

3. Hydracrylic acid in the absence of mineral acids is easily esterified directly with methyl, ethyl, propyl, isopropyl, isobutyl and isoamyl alcohols by using anhydrous copper sulphate as a dehydrating agent. The esters are obtained in 80 per cent to 90 per cent yields.

4. The hydracrylic esters are colorless liquids with faint but characteristic ethereal odor, mostly easily soluble in water ; all below isoamyl are heavier than water ; all are decomposed on boiling at atmospheric pressure, but are distillable without decomposition under diminished pressure.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *The Volumetric Estimation of Lead.*—F. D. Miles has devised a new method for this determination, which depends upon getting the lead into the form of sulphate, decomposing this with hydrogen sulphide, filtering off the precipitate, boiling off the excess of hydrogen sulphide, and finally titrating the sulphuric acid produced in the reaction. The complete conversion of the usual form of lead sulphate into sulphide requires a special treatment with hydrogen sulphide water in a closed flask with the aid of heat and thorough agitation in the presence of fragments of filter paper. The reaction is complete in the presence of calcium sulphate, but barium sulphate prevents a complete conversion when an evaporation with sulphuric acid has been made, so that in its presence the method requires modification. The presence of considerable quantities of iron interferes with the method and necessitates a double separation. The test analyses given by the author show satisfactory results, and he regards the method as preferable to those already in use in its application to ores, but it is evident that the atomic weight of lead is so high that great care is necessary in order to secure accurate results.—*Jour. Chem. Soc.*, cvii, 988. H. L. W.

2. *Search for an Alkali-Metal of Higher Atomic Weight than Cæsium.*—G. P. Baxter has found that pollucite from Paris, Maine, is satisfactorily decomposed by treatment with concentrated nitric acid. Having obtained about 3½ kg. of nearly pure cæsium nitrate from this source, he subjected this large quantity of the rare material to an extensive fractional crystallization. It is probable that a metal beyond cæsium in the group would possess a less soluble nitrate, but the crystallization gave an end

product of about 3 g. which showed no spectroscopic differences from cæsium, and also showed the same atomic weight. At the soluble end the final mother liquor showed the presence of thallium, as well as lithium, sodium, potassium and rubidium. No indication was found of the presence of an unknown element with cæsium in pollucite.—*Zeitschr. anorgan. u. allgem. Chem.*, 1915. H. L. W.

3. *Experimental Organic Chemistry;* by JAMES F. NORRIS. 12mo, pp. 315. New York, 1915 (McGraw-Hill Book Co.). First edition.—This book is designed primarily to be used as a laboratory guide in connection with courses in organic chemistry in which the student follows in the laboratory the subject as developed in the class-room. Directions for experiments illustrating the preparation and chemical properties of all the more important classes of organic compounds are given.. These are very complete and cover several subjects which in many laboratory courses receive scant attention, for example, fatty amines, hydroxyacids, carbohydrates and proteins. Special attention is given to laboratory technique and the handling of small quantities of material. Those properties of a compound which lead to its identification are particularly emphasized. As the companion book for "The Principles of Organic Chemistry" by the same author, this book should prove especially valuable. N. A. SHEPARD.

4. *Laboratory Experiments in Organic Chemistry;* by E. P. COOK. 12mo, pp. 50. Philadelphia, 1915 (P. Blakiston's Son & Co.).—These experiments, which are especially designed for use with Stoddard's "Introduction to Organic Chemistry," constitute the laboratory course in this subject given at Smith College, and are intended to require five to six hours per week for one semester for their completion. The preparations are representative and the numerous test-tube experiments well chosen to illustrate the chemical behavior of the various compounds, as well as to give considerable practice in laboratory technique. N. A. SHEPARD.

5. *The Elements of Physical Chemistry;* by HARRY C. JONES. 8vo, pp. vii, 672, 4th ed., revised and enlarged. New York, 1915 (Macmillan Co.).—In the fourth edition of this well-known text book, some new material has been added, chiefly, however, at the end of chapters, so that the plan of the book has not been changed. This method at times makes statements from former editions a little misleading. For instance, in a list of the "most recent measurements of thermochemistry" (p. 358) the date of the latest reference is 1904. The additions are well chosen and add very materially to the value of the book. H. W. F.

6. *Alcoholometric Tables;* by SIR EDWARD THORPE. 12mo, pp. 91. New York, London, 1915 (Longmans, Green and Co.). —The numbers in these tables are printed in large, clear type and are very convenient for reference. The tables are an extension of those given in the author's "Dictionary of Applied Chemistry." Table I gives the percentages by weight and volume of ethyl alcohol corresponding to specific gravities at

15·6° C./15·6° C. Table II shows the indications of Sikes' hydrometer and the percentages of British proof spirit, American proof spirit, of ethyl alcohol by weight, and also by volume at 15° C. and 15·6° C. Table III compares the indications of Sikes' hydrometer with those of Russia, Holland, Spain, and Switzerland. H. L. W.

7. *Brief Course in Metallurgical Analysis;* by Henry Ziegel. Large 8vo, pp. 72. Easton, Pa., 1915 (The Chemical Publishing Co.).—This small book has about one-half of its pages left blank for notes. A fairly extensive and well-selected list of analyses is outlined, and references are made to the best works on the subject. It appears, however, that the directions given are often not full enough for a student's use, that the language is frequently ambiguous, and that some of the advice given is not the best. H. L. W.

8. *Characteristics of Long Direct-Current Arcs.*—In an earlier paper (see this Journal, vol. xxxviii, p. 362, 1914), W. Grotrian used a direct-current dynamo capable of generating 3 amperes at 5000 volts in demonstrating experimentally that the so-called cyanogen bands owe their origin to nitrogen alone and not to the presence of carbon in the arc. In a more recent paper he has recorded the following interesting results obtained with essentially the same assemblage of apparatus.

The electrical characteristics of arcs, whose lengths were varied from a few millimeters to 50 centimeters, were obtained with carbon, copper, and iron electrodes in air, nitrogen, oxygen, carbon dioxide, hydrogen, and water vapor. It was found that the gas was chiefly responsible for the course of the characteristics while the material of the electrodes had only a very slight influence on the curves.

In all cases where the axis of the arc consisted in a well-defined luminous band the Ayrton formula

$$Vi = \alpha + \beta l + \gamma i + \delta l i$$

reproduced the experimental data very satisfactorily. [$V =$ voltage across arc, $i =$ current, and $l =$ length of arc.] The following numerical results were deduced

air nitrogen	$Vi = 32{\cdot}6l + 62i + 11{\cdot}4li$
carbon dioxide	$Vi = -90 + 73l + 80i + 11{\cdot}7li$
hydrogen	$Vi = 180 + 222l + 290li$
water vapor	$Vi = 185l + 200i + 10li$

As would be expected, the temperature of the core of the arcs was so high that platinum and other metals liquefied in it at once. On the contrary, the little rods of Nernst glowers withstood the high temperature without undergoing appreciable modification and hence they could be used as the terminals of exploring circuits, that is, as electrical sounds. In the air-arc it was found that the potential gradient along the axis of the arc was constant in all parts of the positive column and independent of the length of this region. The potential-fall per centimeter decreased hyperbolically as the current strength increased. The anode and cathode drops were determined directly. The anode-fall was independent of the length of the arc but decreased in the interval between 0·1 and 3 amperes from 150 to 30 volts, the course of the curve being partly dependent upon the material of the anode. The cathode-fall amounted to 20 volts and was independent of the arc length and of the current. It depended very slightly upon the nature of the cathode.

Direct measurements of the cross-section of the arc in carbon dioxide brought out the fact that the current density increased linearly with the field strength.

In the last part of the paper the author advances a theory to account for the conductivity in the arc. It is based primarily on the ionization produced by the collision of electrons whose chaotic thermal velocity exceeds the inferior limit necessary for ionization. By the addition of certain auxiliary hypotheses regarding both the influence of radiation upon the conductivity and the nature of recombination, the theory is developed sufficiently to give the order of magnitude of the observed conductivity. Such details as the limiting of the cross-section of the arc, the course and position of the characteristic in different gases, and the dependence of the characteristic upon pressure are readily explained qualitatively on this theory.—*Ann. d. Physik*, vol. xlvii, pp. 141–196, June, 1915. H. S. U.

9. *Prinzipien der Atomdynamik;* von Dr. J. Stark. III Teil. Die Elektrizität in chemischen Atom. Pp. xvi, 280, with 94 figures. Leipzig, 1915 (S. Hirzel).—As stated in the preface to Part I (see this Journal, vol. xxxii, p. 67, 1911), the atomic structure of matter would be the theme of the third and last Part of the book. By the aid of his valence hypothesis concerning the electrical structure of the surfaces of chemical atoms the author has succeeded in correlating and accounting for a large number of physical and chemical phenomena. A general idea of the scope and contents of the present volume may be obtained from the titles of the five chapters, which are: "Grundlagen der chemischen Atomistik, Gleichgewicht der innermolekularen Bindung, Reaktion der innermolekularen Bindung, Zwischenmolekulare Bindung," and "Optik der Valenzfelder chemischer Atome." H. S. U.

10. *Ten Years' Work of a Mountain Observatory;* by George Ellery Hale. Pp. 99, 66 illustrations. Publication No. 235, Carnegie Institution of Washington, 1915.—This little book contains excellent photographs of the larger instruments which have been installed in the Mount Wilson Solar Observatory and in the associated physical laboratory at Pasadena, together with lucid, concise accounts of the important results obtained with each type of apparatus during the last decade. Good progress in the con-

struction of the large engine for ruling diffraction gratings and of the 100-inch reflector is indicated. It is estimated that this gigantic telescope will reveal about 100,000,000 faint stars hitherto unobservable. Among the problems under investigation may be mentioned solar meteorology, the brightness, motions, distances, and evolution of the stars, the scattering of light in space, and the magnitude and structure of the universe. All of the figures are good, the photographs of spiral nebulæ being especially attractive. The author's style and the subjects presented are of such a nature that the reviewer could not lay the book aside until he had read it through. H. S. U.

11. *The Electrical Nature of Matter and Radioactivity;* by HARRY C. JONES. Third edition. Pp. ix, 212. New York, 1915 (D. Van Nostrand Co.).—A careful comparison, page by page, of the first edition (see this Journal, vol. xxi, p. 465, 1906) with the third shows that the original text has been kept unaltered as far as possible. The comparatively slight changes introduced were necessitated by the conscientious and successful endeavor to bring the experimental data and theoretical considerations up to date. The number of chapters has been reduced by unity by incorporating some of the material from chapter XVIII of the first edition in chapter XVII of the third. The total number of pages has been kept constant by abbreviating the index. It is pleasing to note that this admirably written, semi-popular text has been so well appreciated as to cause it to pass through three editions in a relatively short period of time. H. S. U.

12. *The Book of Wireless;* by A. FREDERICK COLLINS. Pp. xv, 222, with 219 figures. New York, 1915 (D. Appleton and Co.).—In this extremely elementary book the author has endeavored to anticipate and answer all reasonable questions which may arise in the minds of boys or young men who are attempting to assemble and operate either bought or home-made wireless-telegraph sets. He even goes so far as to say: "But if you should have any trouble and if any questions should come up which puzzle you, if you will write to me, I shall gladly do all I can to help you."

The text is divided into three Parts having the following titles: I. "A Small Wireless Outfit" (five chapters), II. "A Long Distance Wireless Set" (four chapters), and III, "Induction Coil, Transformer and Electrolytic Interruptor" (three chapters). The diagrams are large and clear, and the linear dimensions are indicated whenever necessary. At the end of each chapter are given itemized cost lists of parts for both commercial and home-made sets. The last chapter of the volume relates to government rules and regulations, examinations, etc. This is followed by several appendices on wire gauges, drills, types of ærials, etc, a glossary, and an index. The subject matter seems to be very well presented to meet the requirements of the readers for whom it was written. H. S. U.

13. *Plane Geometry;* by C. I. PALMER and D. P. TAYLOR. Edited by G. W. Myers. Pp. v, 277. Chicago, 1915 (Scott, Foresman and Co.).—"The main aim of the authors in the preparation of this text has been to approach abstract reasoning by a method that is natural and comprehensible to the youthful mind, and to vitalize the subject-matter,—making it both interesting and useful through a wide range of practical applications." The salient points of the plans which have been adopted for the attainment of this end may be outlined as follows: (*a*) The experimental or inductive method is used to some extent throughout the book, but it is especially prominent in the earlier pages. After the student has acquired full comprehension of the fundamental propositions he is required to demonstrate them in the classical, formal, deductive manner. (*b*) Actual work in geometry is begun at once without the usual array of definitions, axioms, and principles. In general, formal definitions and axioms are placed in the text at the point where they are first needed, but not until after the student is prepared to appreciate them by having had a partial survey of the subject. (*c*) The exercises constitute one of the most prominent features of the book. They are very numerous (1239), carefully graded, both practical and theoretical, and interesting. (*d*) The proofs of the more difficult as well as of the earlier theorems are given in full, but, as the work progresses, a gradual elimination of proofs is made thereby throwing the student more and more on his own resources. (*e*) The work has been planned so that practical applications may be made as early in the course as possible. To this end, the chapter on areas precedes the one on similarity because it furnishes a great variety of applications to matters of everyday life.

Special care has also been taken to make the pages as useful and attractive as possible. For example, Gothic type and italics are judiciously employed, the line diagrams and half-tone illustrations are neat and clear, a combination linear scale and protractor may be found in a pocket on the inside of the cover, formulas for reference are tabulated, and an index is appended. Unquestionably the book merits the careful consideration of all progressive teachers of elementary plane geometry. H. S. U.

II. GEOLOGY AND MINERALOGY.

1. *Publications of the United States Geological Survey,* GEORGE OTIS SMITH, Director.—Recent publications of the U. S. Geological Survey are noted in the following list (continued from pp. 85–87, July, 1915):

MONOGRAPH, Volume LIII. The Pleistocene of Indiana and Michigan and the history of the Great Lakes; by FRANK LEVERETT and FRANK B. TAYLOR. Pp. 529; 32 pls., 15 figs.

PROFESSIONAL PAPERS.—No. 87. Geology and Ore Deposits of Copper Mountain and Kasaan Peninsula, Alaska; by CHARLES W. WRIGHT. Pp. 110; 22 pls., 11 figs.

No. 95. Shorter Contributions to General Geology. B. Eocene glacial deposits in Southwestern Colorado; by WALLACE W. ATWOOD. C. Relation of the Cretaceous formations to the Rocky Mountains in Colorado and New Mexico; by WILLIS T. LEE. D. An ancient volcanic eruption in the Upper Yukon Basin; by STEPHEN R. CAPPS.

BULLETINS.—No. 544. Fauna of the Wewoka Formation of Oklahoma; by GEORGE H. GIRTY. Pp. 353; 35 pls.

Nos. 566, 569. Results of Spirit Leveling. R. B. MARSHALL, Chief Geographer. No. 566. Utah, 1897 to 1914. Pp. 77. No. 569. Iowa, 1896 to 1913. Pp. 126; 1 plate.

No. 587. Geology and Mineral Resources of Kenai Peninsula, Alaska; by G. C. MARTIN, B. L. JOHNSON and U. S. GRANT. Pp. 243; 38 pls., 43 figs.

No. 591. Analyses of rocks and minerals from the Laboratory of the U. S. Geological Survey 1880 to 1914. Tabulated by F. W. CLARKE, Chief Chemist. Pp. 376.

No. 593. The Fauna of the Batesville Sandstone of Northern Arkansas; by GEORGE H. GIRTY. Pp. 170; 11 plates.

No. 601. Geology and Mineral Deposits of the National Mining District, Nevada; by WALDEMAR LINDGREN. Pp. 58; 8 pls., 8 figs.

No. 602. Anticlinal Structure in parts of Cotton and Jefferson Counties, Oklahoma ; by CARROLL H. WEGEMANN. Pp. 108; 5 pls.

Nos. 611–614. Guidebook of the Western United States. No. 611, Part A. The Northern Pacific Route, with a side trip to Yellowstone Park; by MARIUS R. CAMPBELL, and others. Pp. 212 ; route map (in 27 sheets), 27 pls., 38 figs. No. 612, Part B. The Overland Route, with a side trip to Yellowstone Park ; by WILLIS T. LEE, R. W. STONE, H. S. GALE and others. Pp. 244 ; 25 maps, 49 pls., 20 figs. No. 613, Part C. The Santa Fe Route, with a side trip to the Grand Canyon of the Colorado ; by N. H. DARTON and others. Pp. 194. No. 614, Part D. The Shasta Route and Coast Line ; by J. S. DILLER and others. Pp. 142.

No. 620–B. Nitrate Deposits in Southern Idaho and Eastern Oregon ; by G. R. MANSFIELD. Pp. 44; 2 pls , 2 figs.

WATER-SUPPLY PAPERS. No. 340–K. Stream-gaging Stations. Part XI. Pacific Coast Basins in California ; compiled by B. D. WOOD. Pp. xx, iv, 131–146.

No. 342. Surface Water Supply of the Yukon-Tanana Region, Alaska ; by C. E. ELLSWORTH and R. W. DAVENPORT. Pp. 343; 13 pls., 5 figs.

Nos. 356, 357. Surface Water Supply of the United States 1913. N. C. GROVER, Chief Hydraulic Engineer. No. 356. Part VI. Missouri River Basin. Pp. 291; 2 plates. No. 357. Lower Mississippi River Basin. Pp. 86; 2 pls.

No. 358. Water Resources of the Rio Grande Basin 1888–1913; by R. FOLLANSBEE and H. J. DEAN. Also Surface Water

Supply of the United States, Part VIII, Western Gulf of Mexico Basins. Pp. 725; 3 pls.

Nos. 375, B, C, D, E. Contributions to the Hydrology of the United States, 1915. Pp. 51–130.

2. *Relation of the Cretaceous Formations to the Rocky Mountains in Colorado and New Mexico;* by WILLIS T. LEE. Prof. Paper 95-C, U. S. Geol. Surv., 1915, pp. 27–58, pl. V, text figs. 12–22.—A carefully wrought out paper showing that the present Rocky Mountains in Colorado, New Mexico, and Wyoming did not exist as such in late Mesozoic time, and that these areas were covered with many thousands of feet of Cretaceous strata. There were no granitic island masses in the Cretaceous sea of Colorado, as held by some geologists. These results have a direct bearing on the problem of the Cretaceous-Tertiary boundary in the Rocky Mountain region. The author says: "Certain conglomerates that rest unconformably on Cretaceous beds are regarded as basal Tertiary by some geologists and as Cretaceous by others. These conglomerates contain great numbers of pebbles of crystalline and metamorphic rocks such as are now found in the mountains, and they are so distributed as to prove that they were derived from the present mountainous areas. Inasmuch as the Cretaceous formations were originally continuous over the site of these mountains, it follows that there must have been uplift and erosion sufficient to remove them and to reach the pre-Cretaceous rocks before the materials for the conglomerates could be obtained. In the Rocky Mountain region of Colorado and New Mexico all deposits above these conglomerates are of the nonmarine type that characterizes the undisputed Tertiary formations of the same regions" (p. 57). He then concludes: "It naturally follows that the conglomerates and other sediments derived by erosion from the newly uplifted mountains—such as those of the Denver, Arapahoe, Dawson, Raton, and related formations—belong to the Tertiary system" (p. 58). C. S.

3. *Conceptions regarding the American Devonic;* by JOHN M. CLARKE. N. Y. State Mus., Bull. 177, 1915, pp. 115–133.—An excellent paper, written in Clarke's characteristic style and prepared to commemorate the seventieth birthday of the European authority on the Devonian, Professor Emanuel Kayser. It brings within a small compass much of our knowledge of the American Devonian sequence and distribution, and its correlation with the occurrences of the Devonian in the rest of the world. C. S.

4. *Fauna of the San Pablo Group of Middle California;* by BRUCE L. CLARK. Univ. Calif. Pub., Bull. Dept. Geology, vol. 8, No. 22, 1915, pp. 385–572, pls. 42–71.—This work brings together all that is known of the Upper Miocene strata and fauna of Middle California. There are 165 species, and of these 135 (72 new) are determinable molluscs; 32 are living (21 per cent). C. S.

5. *The Cretaceous Sea in Alberta;* by D. B. DOWLING. Trans. Royal Soc. Canada, ser. III, vol. ix, 1915, pp. 27–42,

11 pls.—This good paper summarizes what is known of the succession, physical character, and distribution of the various formations of the Cretaceous period in Alberta. Of great value are the ten paleogeographic maps showing the extent of the western land, the marine, brackish-water, and continental deposits. It is to be hoped that the author will continue his studies northward and present his conclusions as to the extent of the various formations into the Arctic Ocean. C. S.

6. *Wabana Iron Ore of Newfoundland;* by ALBERT ORION HAYES. Canada, Geol. Surv., Memoir 78, 1915, pp. 163, 28 pls., 4 text figs.—This excellent report shows that the bedded iron ores of eastern Newfoundland (Bell island) are of early Ordovician age (Arenig), though they have long been considered of Silurian (Clinton) time. The greater part of the work is devoted to the genesis of the iron ores, which were deposited in a shallow agitated sea devoid of limestones and igneous rocks. The little lime present in the ore (2·5 per cent) occurs in the form of fossils. "The phosphorus of the ore is also derived from the remains of organic life preserved in it. No evidence of diagenetic transformation from an original oolitic limestone to an oolitic iron ore has been found and no concentration of iron has occurred since the deposition of these ferruginous sediments. They are primary bedded iron ore deposits, mined to-day in essentially the same condition except for induration, faulting, and the addition of small amounts of secondary calcite and quartz in fault cracks, as when they were laid down" (page 93). C. S.

7. *The Yukon-Alaska International Boundary, between Porcupine and Yukon Rivers;* by D. D. CAIRNES. Canada, Geol. Surv., Memoir 67, 1914, pp. 161, 16 pls., 2 text figs., 2 maps.—The author describes the living flora and fauna, the topography, geology, and sedimentary sequence of a narrow belt between the Yukon and Porcupine rivers along the 141st meridian on the International Boundary between Canada and the United States. The greater portion of the Paleozoic sequence is well developed here, and as a rule the deposits are limestones and dolomites. Doctor Cairnes is to be congratulated on having brought out considerable of the detailed sedimentary sequence. C. S.

8. *The Ordovician Rocks of Lake Timiskaming;* by M. Y. WILLIAMS. Canada, Geol. Surv., Mus. Bull. No. 17, 1915, pp. 8, 1 pl., 1 text fig.—The author records the first finding of Black River limestones with fossils beneath this Silurian remnant of once widely distributed formations. C. S.

9. *Structural Relations of the Pre-Cambrian and Palæozoic Rocks North of the Ottawa and St. Lawrence Valleys;* by E. M. KINDLE and L. D. BURLING. Canada, Geological Survey, Mus. Bull. No. 18, 1915, pp. 23, 2 pls., 6 text figs.—The authors point out that the abrupt elevation of the Laurentian plateau ("Laurentian Plateau escarpment") above the horizontal lowlands of the Ottawa and St. Lawrence valleys represents a fault line scarp. The early Paleozoic strata are as a rule here faulted down, and

in the lowlands have been preserved from denudation; accordingly "the Palæozoic seas extended very widely, if not completely, over the Laurentian upland southeast and east of Hudson bay." The paper is a valuable contribution toward a better understanding of the paleogeography of Ordovician, Silurian, and Devonian times. C. S.

10. *Geology of Franklin County;* by A. M. Miller. Ky. Geol. Surv., 4th series, vol. 2, 1914, pp. 7–87.—This excellent report maps and describes in great detail the various Ordovician formations of Franklin County, central Kentucky. The Mohawkian series is divided into nine members, and the Cincinnatian into five. Commonly the Eden is regarded as at the base of the Cincinnatian series, but in this report the Cynthiana is the foundation, a formation unknown in the standard section of New York. The soils of the county are described in an additional paper (pages 89–144) by S. C. Jones. C. S.

11. *Revision of the Tertiary Mollusca of New Zealand;* by Henry Suter. New Zealand Geol. Surv., Palæontological Bull. No. 2 (Part I), 1914, pp. 64, 17 pls.; No. 3 (Part II), 1915, pp. 69, 9 pls.—In these publications all of the new species defined many years ago by Captain F. W. Hutton and others are revised in the light of modern knowledge of the Recent Mollusca. They comprise a first step toward a revision of the Tertiary Mollusca of New Zealand. C. S.

12. *Third Appendix to the Sixth Edition of Dana's System of Mineralogy;* by William E. Ford. Completing the work to 1915. Pp. xiii, 87. New York, 1915 (John Wiley & Sons).—This third appendix to Dana's System has been prepared by Prof. W. E. Ford, to whom the science owes also the completion of Appendix II, seven years ago. Notwithstanding the fact that mineralogy is sometimes regarded as the most nearly complete of all the sciences, descriptions of new occurrences still go on actively and no fewer than one hundred and eighty new names have been added between 1908 and 1915; of these about one-third are regarded by Professor Ford as probably well established species. This Appendix follows the lines laid down in its predecessors, but special attention is given to the literature of X-rays and crystal structure.

III. Miscellaneous Scientific Intelligence.

1. *Publications of the Carnegie Institution of Washington.*—Recent publications of the Carnegie Institution are noted in the following list (continued from p. 94, July, 1915):

No. 85. Index of Economic Material in Documents of the States of the United States; New Jersey (1789–1904). Prepared for the Department of Economics and Sociology by Adelaide R. Hasse. Pp. 705, 4to.

No. 175. Researches of the Department of Terrestrial Magnetism. Volume II. Land magnetic observations, 1911–1913, and reports on special researches; by L. A. Bauer and J. A. Fleming. Pp. v, 278; 13 pls., 9 figs.

No. 207. The Permo-Carboniferous Red Beds of North America and their Vertebrate Fauna; by E. C. CASE. Pp. iii, 176; 24 pls., 50 figs. To be noticed later.

No. 209. Acidity and gas interchange in Cacti; by HERBERT M. RICHARDS. Pp. 107.

Nos. 211, 212. Papers from the Department of Marine Biology. No. 211, vol. VII. Homing and related activities of birds; by J. B. WATSON and K. S. LASHLEY. The acquisition of skill in archery; by K. S. LASHLEY. Pp. 128; 9 pls., 19 figs. No. 212, vol. VIII. Contains nine papers by F. A. POTTS, H. L. CLARK, GRACE MEDES and others. Pp. 256; 23 pls., 73 figs.

Nos. 221, 222. Contributions to Embryology. No. 221, vol. I, No. 1. On the fate of the human embryo in tubal pregnancy; by F. P. MALL. Pp. 103, 4to; 11 pls., 24 figs. No. 222, Nos. 2–6. Pp. 108, 4to; 10 pls., 25 figs. Contains the following: Description of two young twin human embryos with 17–19 paired somites; by JAMES C. WATT. An anomaly of the thoracic duct with a bearing on the embryology of the lymphatic system; by ELIOT R. CLARK. Fields, graphs, and other data on fetal growth; by A. W. MEYER. The corpus luteum of pregnancy, as it is in swine; by GEORGE W. CORNER. Transitory cavities in the corpus striatum of the human embryo; by CHARLES R. ESSICK.

OBITUARY.

M. JEAN HENRI FABRE, the eminent entomologist, known the world over for his delightful descriptions of the habits and lives of insects, died on October 11 at the advanced age of ninety-two. He has been called a poet as well as a naturalist and the interesting story of his life has been well told in a recent volume by C. V. Legros (see vol. xxxvii, 284).

DR. THEODOR BOVERI, the eminent German biologist, since 1893 professor of comparative anatomy and zoölogy at Würzburg, died recently at the age of fifty-three years.

HENRY GWYN JEFFREYS MOSELEY was killed in action at the Dardanelles on August 10 at the age of twenty-seven years. He was the son of Professor H. N. Moseley of Oxford, and though so young had already given proof of his rare intellectual gifts; he was particularly interested in physical investigations and had done important work on the X-ray spectra of rare earths and the study of crystal structure by X-rays.

PROFESSOR D. T. GWYNNE-VAUGHAN, the distinguished plant anatomist of Reading, England, died on September 4 at the age of forty-four years.

WILLIAM WATSON, secretary of the American Academy of Arts and Sciences since 1884 and an authority on technical education, died in Boston on September 30 in his 82d year.

AUGUSTUS JAY DU BOIS, professor of civil engineering in the Sheffield Scientific School of Yale University, died on October 19 in his sixty-seventh year.

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FOURTH SERIES

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[FOURTH SERIES.]

Art. XLI.—*A Metallographic Description of Some Ancient Peruvian Bronzes from Machu Picchu;* by C. H. Mathewson.

[Contribution from the Hammond Laboratory of the Sheffield Scientific School, Yale University.]

Introduction.

I am indebted to Professor Hiram Bingham for an opportunity to examine the ancient Peruvian bronzes collected at Machu Picchu by the National Geographic Society-Yale University Peruvian Expedition of 1912 (1).* The structures exhibited by objects of this character are of interest not only to metallographists but also in archæological circles, inasmuch as certain definite facts concerning the methods used in shaping the objects can be learned from the structural examination. Such work, however, necessitates some mutilation of the specimens, which doubtless accounts for the scarcity of metallographic work devoted to rare objects. Collectors frequently submit their specimens for chemical analysis, since this merely involves the preparation of a small sample by drilling, while the scope of the forthcoming information is known in advance and the undertaking can be intelligently provided for. Metallographic examination, on the other hand, may yield much or little information and generally necessitates subsequent restoration of the object.

As to the character of the information likely to be obtained by the use of metallographic methods, the following general

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* For references here and on later pages, see the Bibliography at the end of this article.

statements may be of service to those who are unfamiliar with this class of work:*

1. An unaltered cast structure can be recognized at once and a qualitative distinction between rapidly cooled metal, e. g., metal cast in a small unit, and slowly cooled metal, e. g., metal from a casting of considerable size, can be made.

2. An annealed casting can be distinguished from an unannealed casting, but such annealing would serve no useful purpose in small bronzes of low tin-content and, in any case, would hardly be undertaken except as a preliminary to other operations resulting in more or less complete obliteration of the casting structure.

3. Mechanical alteration of a cast piece, or of a piece with more extended but not necessarily known past history, by rolling, hammering, etc., can be detected with certainty provided the piece has been worked with considerable intensity. A few gentle blows with the hammer, a bend, or a twist, would not alter the visible structure of the metal, but mechanical treatment resulting in pronounced change of form gives rise to characteristic structural changes as well. These effects do not, however, serve to differentiate at all sharply between different forms of mechanical treatment, whether by rolling, hammering, etc. It seems necessary to rely mainly upon surface observations for evidence of this character. Under the influence of mechanical treatment, the metal stiffens and gradually loses its ductility until, eventually, further change of form cannot be brought about without fracture. The precise nature of these changes cannot be detected by observations under the microscope. Certain coincident effects, such as elongation and etching peculiarities of the crystalline grains, serve, together with physical tests, to establish the worked condition of the metal.

4. Annealing restores the ductility by producing an entirely new growth of grain in which certain unfailing characteristics may be recognized. Thus, a recrystallized bronze can be recognized at once and the evidence of previous mechanical treatment, with following anneal, is thereupon complete. The nature of the recrystallization, whether fine- or coarse-grained, localized or evenly distributed, incipient or sufficiently developed to entirely obliterate the pre-existing structure, depends upon the composition of the metal, the nature, intensity and distribution of the mechanical treatment, as well as the temperature and dura-

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* Ample discussion and illustration of these statements will be given in ensuing portions of this paper.

tion of the anneal. Fortunately, careful study of the recrystallization phenomena in a particular group of alloys, such as the present group of alpha-bronzes (see discussion of constitution, p. 540), leads to certain associations and generalizations so that the treatment resulting in a given structure may frequently be specified without the too free admission of bewildering assumptions and conditional premises. Certain shortcomings must, however, be admitted. For example, a ductile object may be lengthened at will by intensive rolling, drawing, or hammering, if an adequate number of intermediate softenings, or annealing, operations are conducted. The final structure and physical properties are determined by the last co-ordinated draft and anneal unless unusually light mechanical or annealing treatment has prevailed. No knowledge of preceding operations can ordinarily be derived from the structural characteristics at this point. If the duration of the last anneal is approximately known, the temperature region of annealing may be estimated from the mean grain size. Some distinctions can be made without regarding the time factor, e. g., an anneal at bright red heat can be distinguished from one at nascent red, since the coarse grain produced in a very few minutes at the higher temperatures is not much affected by longer exposure and cannot be duplicated by even a very prolonged anneal at the lower temperature. It has thus been possible to fairly estimate the temperature which must have been reached in the finishing anneal of some of these old bronzes.

While, in completely recrystallized structures, the grain characteristics give no indication of the total extension of the piece or the number of stages in the process, partially recrystallized structures, in which traces of the cast condition are apparent, indicate that the finished piece corresponds closely in form to the original castings. Thus, a number of the bronzes examined were obviously cast in the rough and wrought into shape, the process requiring a moderate amount of work and a limited number of annealing operations; perhaps only one.

5. Drastic treatment whereby the object, by successive drafts and anneals, suffers manifold extension in one direction or another may sometimes be recognized by characteristic migrations of insoluble impurities which have remained sensibly unaffected during the heat treatment. Such evidence is purely qualitative, since the extension of individual units within the moving mass is not proportional to the extension of the piece

as a whole. Most of the bronzes contain sulphur in small amount which, from the chemical relationships involved, must occur in the form of cuprous sulphide. In the thin, flat bronze knives of the collection, the particles of cuprous sulphide are elongated to a degree attainable only through several successive drawing and annealing operations. A copper knife of similar form contains in the neighborhood of one per cent of cuprous oxide which, in the broader and thicker parts of the specimen, occurs in normal eutectic form as small globules characteristically grouped throughout the copper matrix. In the intensively worked parts of the specimen, notably the blade, each group of oxide particles has been dragged out into a continuous train which gives the appearance of a dotted line in the photomicrograph (fig. 71).

6. Positive identification of hot-worked metal is not always possible, since, in hot-working at effective temperatures, the deformation is followed by recrystallization as in the anneal of cold-worked metal. Variables of the same character affect the result. In hot-working, however, recrystallization always takes place at temperatures* which would produce relatively coarse grain if time enough were allowed. Thus, the grain size is determined mainly by the time available for recrystallization between the blows, or after working has ceased. With small specimens, this is almost invariably brief, since the small mass of metal cools rapidly. Upon re-heating, a coarser grain will develop a relatively coarse grain while other portions are work the whole mass of metal simultaneously, attention will first be directed to some particular portion which will later develop. Since, with primitive facilities, it is impossible to being worked. This results in a highly non-uniform conglomerate. Hot working is, therefore, indicated where coarse and fine grains are found closely associated and where neighboring parts of the specimen exhibit wide variation in grain size.

The foregoing statements will indicate in a general way what manner of conclusions may be drawn from metallographic examination as applied to metal of sensibly uniform composition throughout, viz., in the case of pure metals or solid solutions. Some of these statements will be elaborated further on

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* Where both hot-working and cold-working are permissible, as in the case of these alpha bronzes, the former is undertaken in order to avoid the necessity of annealing between stages of intensive working, i. e., the metal stays soft, owing to rapid recrystallization and relief of strain, if the temperature is high enough. A full red-heat is required for continued softness under a rapid succession of blows.

and the specific application of the principles involved will be given in individual descriptions of the several objects.

Additional characteristics are encountered when constitutional changes occur during thermal treatment of the metal, i. e., when the alloy is made up of two or more distinct structure elements differing in composition and subject to influences affecting their composition, distribution, or even identity. These characteristics may be used, in conjunction with the others already mentioned, to supply some knowledge of the past history of the object. A brief discussion of constitutional relationships between tin and copper will be introduced shortly, along with a table of analyses pertaining to the present set of bronzes. To further the immediate appreciation of prevailing conditions, it may be observed at this point that, while all of the bronzes examined are normally composed of a single structure element, the alpha solution of tin in copper, certain secondary constituents of a transitory nature occur in the cast metal.

Aside from the purely micrographic aspects of the work, some facts of interest may be learned from first hand observation. Thus, certain of the objects, notably the long cloak pins, show surfaces which may be closely simulated in wood by whittling; the separate surface elements are approximately flat and long enough in some cases to indicate the use of a very broad-faced hammer or even a rolling face in shaping the metal. One large pin has a flattened head bearing a single perforation, which, from its eccentricity and decreased diameter on one face, must have existed before the head was flattened. (A cylindrical hole starts to close on the hammered face.) Duplex objects, in which different parts are joined mechanically, by welding, or by duplex casting, may sometimes be recognized by superficial examination. A case of the last named variety was found in the present collection. Where surface indications are not adequate, examination of a properly selected section will serve to settle the question.

The archæologist will doubtless be inclined to look through these pages for some expression as to the probable age of the bronzes. Unfortunately, no inferences of this sort can be drawn from examinations of this character, or from any other form of examination, as far as I am aware. The rate of oxidation, or patina formation, depends upon the purity and structural condition of the metal, but no laws governing the process have been formulated. Cast structures are more porous and structurally less homogeneous than worked structures and oxidize more rapidly (cf. descriptions of Objects No. 2 and No. 5). Certain structure elements are attacked selectively on long exposure to atmospheric influences.

Garland (2) concludes from examination of some ancient Egyptian bronzes that some recrystallization of worked portions has very likely been effected by ageing. Rose (3) points to possible recrystallization of an old trial plate of gold used as an assay standard in the Royal (British) Mint. Such conclusions are interesting but they are based wholly upon circumstantial evidence. I have observed cases of incipient recrystallization of vigorously worked metal in the present collection of bronzes, but precisely the same effect may be produced by a form of annealing which is clearly indicated from other considerations. Cf. description of Object No. 3; in particular, photo-micrograph No. 48. In other cases, the very fine recrystallized grains show deformational characteristics which proves that they were produced by the original craftsmen, e. g., Object No. 16. Numerous mechanically hardened and subsequently unaltered (by perceptible recrystallization) structures were observed. In no case does it seem necessary to resort to ageing for an explanation of the structures observed in these bronzes. Whatever the actual facts involved, any eventual reversion of unstable, mechanically hardened, structures to more stable (recrystallized) form cannot be defined as a determinate function of the time involved in the transformation.

It must likewise be conceded that metallographic examination of the finished object cannot be expected to furnish any clue to the smelting process used in preparing the metal or, indeed, to indicate whether the alloy was produced directly by smelting a mixed ore, or by alloying tin and copper.

SUMMARY OF ANALYSES AND STRUCTURAL EXAMINATION.

The present collection embraces about one hundred articles which may be classed as tools, including axes, hatchets, knives, chisels, bars and pointed instruments; domestic implements, including mirrors, tweezers, small knives, pins or needles, spatulas or spoons and various small articles ornamentally cast; articles of adornment, such as rings, bracelets, spangles, bells, etc.; and crude, or irregular pieces. A number of specimens (thirty-three in all) intended to approximately represent the diversity of the collection were analyzed. Twenty-one of these were cut into appropriate sections and examined structurally. The latter are illustrated from drawings in figs. 9 to 29. A general summary of analytical data is given in Table I, and metallographic data, with references to photo-micrographs, in Table II.

TABLE I.

No.	Character and Weight of Object.	Cu	Sn	Ag	Fe	S	
1	Knife, T-form. Weight, 26g.	94.26	4.82	-----	0.32	0.23	------
2	Spatula-shaped object. Ornam. head, bird-form	86.03	13.45	-----	---	---	Zn–0.32
3	Cloak-pin, star head. 37g.	95.99	3.60	-----	---	tr.	------
4	Ball. 35g.	96.90	2.11	0.81	---	---	------
5	Ornam. knife. Fisher-boy. 41g.	88.08	9.39	-----	---	---	Zn–0.17
6	Chisel. 224g.	96.20	3.71	-----	---	---	------
7	Knife, T-form. Llama head, 20g.	96.79	3.00	tr.	---	tr.	------
8	Axe, broken short below head. 242g.	93.70	5.01	-----	0.87	0.44	------
9	Thin, flat copper knife, T-form. 22g.	99.73	----	-----	---	tr.	------
10	Axe, broken short 1″ above edge. 62g.	94.41	5.12	-----	---	0.29	------
11	Cloak pin, pierced flat head. 37g.	96.38	3.92	-----	---	---	------
12	Hand mirror. 72g.	94.35	5.34	-----	---	---	------
13	Tweezers, in process of manufacture. 9g.	90.05	9.72	-----	---	---	------
14	Thin, flat knife, T-form. 21g.	96.26	3.67	tr.	---	0.18	------
15	Axe with double-branched head. 414g.	95.63	3.99	0.37	---	0.40	------
16	Chisel, twisted and broken short. 100g.	93.90	5.53	-----	0.06	0.15	------
17	Irregular mass. 286g.	95.68	4.20	-----	---	---	------
18	Large, crude needle. 61g.	94.69	5.16	-----	---	---	------
19	Tweezers. 3g.	94.69	5.53	-----	---	---	------
20	Large bar. 1070g.	94.52	5.45	-----	---	tr.	------
21	Light rectangular piece. 20g.	94.42	5.96	-----	---	---	------
22	Thin, flat knife, T-form. 9g.	95.35	4.22	-----	---	0.20	------
23	" " " " 32g.	94.70	6.60	-----	---	tr.	------
24	" " " " 10g.	90.09	8.99	0.68	---	0.13	------
25	" " " " 49g.	92.55	7.14	tr.	---	0.20	------
26	" " " " 46g.	94.52	5.12	tr.	tr.	0.29	------
27	" " " " 18g.	95.03	5.12	tr.	---	tr.	------
28	Small bar. 32g.	92 06	7.30	0.31	---	---	------
29	Small rod. 8g.	93.21	6.90	-----	---	---	------
30	Irregular wrinkled sheet. 160g.	----	99.79	-----	---	---	Sb–0.08
31	Thin knife blade. 6g.	91.24	8.89	tr.	tr.	0.37	------
32	Small silver disc (spangle). 0.77g.	----	----	100.	---	---	------
33	" " " " 0.96g.	----	----	99.5	---	---	Pb–tr.

The analyses shown in Table I were made in the Sheffield Chemical Laboratory by Mr. Frank G. Mooney under the supervision of Professor H. W. Foote. After a preliminary qualitative examination of each object, the elements indicated were determined quantitatively according to standard methods.

Some of the bronzes are remarkably pure, aside from small quantities of sulphur in the form of cuprous sulphide. This

TABLE II.

Brief Summary of Metallographic Examination.

No.	Object	Illustration	Portion Examined	Photo-Micrograph	Structural Characteristics	Probable Treatment	Number of Grains*
1	Knife	Fig. 9	Longitudinal section from end to end	Fig. (36), 37, 38, 39	Predominant casting structure with local deformational characteristics	Cast to approx. final form. Worked locally with light intermediate anneal. Finished stiff in shank and blade	Indeter. in original state. After 30m. anneal at 700°, in shank—23
2	Spatula or spoon	Fig. 10	Longitudinal section from end to end	Fig. (40), 41, 41, 42, 43, 44, 45	Cast structure throughout figure of bird, severely deformed in attenuated bill. Distinguishable cast str. in spatula end but considerably altered by deformation and incipient recrystallization	Cold-worked at extremities with very light intermediate local anneal	
3	Cloak pin, Star head	Fig. 11	Isolated sections along principal axis	Fig. (46), 47, 48, 49	Succession of changing structures passing from the normal cast head to the completely recrystallized point	Shank extended by cold-working. Annealed with decreasing intensity from point towards head (thrust part way into fire). Finished stiff and hard	Several inches from point—33
4	Ball	Fig. 12	Section through center	Fig. (50), 51, 52	Typical cast structure with congenital (?) twins in a region of special configuration		

* Average number of grains counted along $3\frac{1}{2}''$ line at a magnification of 72×.

TABLE II—*Continued.*

Brief Summary of Metallographic Examination.

No.	Object	Illustration	Portion Examined	Photo-Micrograph	Structural Characteristics	Probable Treatment	Number of Grains*
5	Knife Fisher-boy	Fig. 13	Section through the prostrate figure. Tip of blade	Fig. (53), 54	Typical cast structure except in the blade, which shows the effect of cold-working with preceding light anneal. Badly oxidized specimen	Worked in the blade with some intermediate light annealing treatment	
6	Chisel	Fig. 14	Sections through the butt and chisel edge	Fig. (55), 56, 57, 58, (59), 60, (61), 62, (63), 64	Coarse and fine recrystallized grain closely associated near the edge. Coarse, but highly irregular grain elsewhere	Worked at bright red heat at least near the edge. Finished below the recrystallization range	One inch from the chisel edge —13
7	Knife Llama-head	Fig. 15	Longitudinal section through the head and a portion of the shank	Fig. (65), 66, 67	A duplex piece in which the material of the blade reaches to the other extremity where it forms a core around which the main substance of the llama head is cast in metal of different composition, not sensibly altered by subsequent treatment. The core, with shank and blade, was worked into shape by usual methods		Core—18
8	Axe	Fig. 16	Corner section from broad end	Fig. (68), 69	Especially characterized by coarse grain and a large amount of sulphide	Worked lightly at the broad end. Annealed at full red heat	In single portion examined—10
9	Copper knife	Fig. 17	Cross sections through the blade parallel to handle at center and near tip	Fig. (70), 71, 72	Eutectic distribution of oxide particles materially altered by extension. Recrystallization showing subsequent anneal	Worked from rough T-shaped piece with much extension in blade	

* Average number of grains counted along 3½″ line at a magnification of 72 ×.

TABLE II—*Continued.*

Brief Summary of Metallographic Examination.

No.	Object	Illustration	Portion Examined	Photo-Micrograph	Structural Characteristics	Probable Treatment	Number of Grains*
10	Axe	Fig. 18	Section perpendicular to edge	Fig. (73), 74, 75	Coarse recrystallized grain showing severe deformation near edge	Cold-worked with intermediate annealing at full red heat	In single section examined—13
11	Cloak pin, flat head	Fig. 19	Natural flat surface of head rubbed down for examination	Fig. (76), 77	Coarse recrystallized grain showing marked deformational characteristics	Head flattened by hammering with annealing treatment at full red heat. Finished hard	Average of part examined—15
12	Hand Mirror	Fig. 21	Cross section passing through major axis of handle	Fig. (78), 79, 80	Partially homogenized casting structure in handle. Complete recrystallization elsewhere	Handle preserves its cast shape. Body of object worked extensively with light annealing	Average for body of mirror—22
13	Tweezers in process	Fig. 22	Longitudinal section from end to end	Fig. (81), 82	Partially homogenized recrystallized structure with considerable variation in grain size	Moderately worked piece with light annealing treatment	13 to 25
14	Thin, flat knife	Fig. 20	Section through hook-shaped extremity of handle	Fig. (83), 84, 85	Particularly characterized by pronounced extension of the sulphide particles in the direction of rolling	Drastic treatment perhaps by a form of rolling with the necessary intermediate annealing operations	Average for handle—25
15	Axe with two-armed head	Fig. 23	Extremity of one arm	Fig. (88), 89	Uniformly recrystallized. Deformational characteristics	Cold-worked with intermediate annealing treatment. Last anneal at dull red heat. Finished hard all over	In single section examined—28

* Average number of grains counted along 3½″ line at a magnification of 72 ×.

Table II—*Continued.*

Brief Summary of Metallographic Examination.

No.	Object	Illustration	Portion Examined	Photo-Micrograph	Structural Characteristics	Probable Treatment	Number of Grains*
16	Chisel	Fig. 24	Longitudinal section near lateral edge	Fig. (90), 91, 92	Prominent cores. Incipient recrystallization in all parts. Strong deformational characteristics	This specimen has never lost its cast structure entirely. It was worked vigorously with at least one very light anneal. Hardest specimen examined	55
17	Irregular mass	Fig. 25	Section through piece near one end	Fig. (93), 94, 95	Casting structure with occasional twin formation	Slowly cooled or reheated	
18	Large needle	Fig. 26	Section through eye	Fig (96), 97	Completely recrystallized. Prominent deformational characteristics in vicinity of eye	Eye formed by looping the end of rod and closing with lateral flaps	22
19	Tweezers	Fig. 27	Longitudinal section after straightening to form of 13		Prominent cores. Fine-grained recrystallized secondary structure similar to that shown in Fig. 91	Cold-worked with light annealing treatment	
20	Large bar	Fig. 28	Cross section near one end		Completely recrystallized. No trace of cores. Metal very defective, containing numerous cavities bearing evidence of oxidation	Extensively worked with much annealing treatment. Finished moderately hard	22
21	Small rectangular piece	Fig. 29	Longitudinal section near lateral edge		Completely recrystallized and in annealed condition	Cold-worked with annealing treatment	32

* Average number of grains counted along $3\frac{1}{2}''$ line at a magnification of 72 ×.

constituent was identified metallographically (cf. observations on cuprous sulphide in copper by Heyn and Bauer (4)) in every bronze examined, although sulphur was not reported in a number of the analyses.* One specimen, No. 8, contains nearly a per cent of iron and another, No. 4, contains about the same quantity of silver. Others contain smaller percentages of these elemnts, while small amounts of zinc were found in two specimens. The rest of the bronzes contain practically no metallic impurities. Two silver discs are also very pure, one containing a trace of lead.

Perhaps the most noteworthy specimen is No. 30, which consists of very nearly pure tin. Other specimens were found in which strips of the metal were rolled into the form of a ball, presumably intended for convenience in cutting small pieces to alloy with copper. This metal was not analyzed but it is unquestionably tin of good quality. Probably the discovery of these specimens constitutes the first direct proof that Inca metallurgists were acquainted with tin in elementary form. It is fair to infer that they used it in preparing their bronzes.

On the other hand, it is certainly true that the proportion of tin present in any given case has not been chosen with particular regard to the use for which the object must have been intended. The largest percentage of tin was found in a small spatula- or spoon-shaped object (No. 2) which is particularly distinguished by a perfectly executed cast figure of a humming bird at the extremity of the handle. This specimen contains 13.45 per cent tin. Next in order, we have another artistic casting representing a prostrate fisher-boy with line and fish which, although worked (mildly) into a blade below the figure (cf. fig. 13), could never have been intended for severe use. This object contains 9.39 per cent tin. The ordinary axes and knives, which would seem to require high percentages of tin to give them maximum hardness and strength, carry from 3 to 9 per cent of this element, most of them in the neighborhood of 5 per cent. One knife, No. 9, is composed of very nearly pure copper. Boman (5) points out similar anomalous relationships in discussing a table of some 65 analyses representing the compositions of various objects found in Argentina, Bolivia, Peru, and Ecuador.

* When we consider that one part by weight of sulphur yields about five parts of cuprous sulphide, the constituent which appears under the microscope as a distinct structure element, it is apparent that the micrographic method may well be superior to methods of chemical analysis in detecting small quantities of sulphur in bronze.

At first sight, these facts seem to indicate that the Inca bronzes were produced by smelting mixtures of tin and copper ores, since, by such a process, it would be difficult to control the composition of the resulting alloy. According to Joyce (6), "it seems almost certain that the presence of tin is accidental, since it is found in greatest quantity in those implements which require it least."

I have already remarked that metallographic testing methods cannot be expected to furnish any clue to the manner in which tin and copper were brought into association. Without additional facts of more direct application, it does not appear possible to prove the genesis of these bronzes. I wish, however, to draw attention to a few general considerations which have strengthened my belief that the present objects were produced by alloying the metals, tin and copper, after obtaining them in comparatively pure form.

In the first place, both tin and copper were known in elementary form and the former metal must have led a transitory existence (as raw material for use in bronze making), since no finished objects of tin have been found in Inca ruins or burial places. From a metallurgical standpoint, while it is true that tin and copper occur closely associated in some Peruvian ores, I find it difficult to believe that these primitive people could have smelted mixed ores which would almost certainly contain other metals (lead, zinc, silver) and, very likely arsenic and antimony, as well as sulphur, so as to produce the remarkably pure copper-tin alloys in question. A private communication from Mr. D. C. Babbitt, of the Cerro de Pasco Mining Co., contributes analyses of table concentrates from Peruvian sources showing copper and tin in association together with silver, gold, tungsten, zinc, antimony, arsenic, sulphur and earthy material. These complex concentrates are handled with reluctance by the highly equipped smelters of Swansea (Wales), on account of smelting difficulties. Mr. Edmond A. Guggenheim, who has taken considerable pains to gather metallurgical opinions from his associates in South America, calls attention in a recent letter to the frequent occurrence of tin and copper in chemical or mineralogical combination; but on the other hand, to the frequent occurrence of lodes carrying copper ores in association with tin ores. This is true of the Bolivian tin-fields in which tin predominates over the copper. He also refers to the difficulty of smelting the associated ores, stating that in Cornwall, even in very remote times, the two classes of ores were separated before smelting.

It is far easier to believe that the Incas learned to recognize certain characteristic copper and tin minerals which were carefully hand-picked and smelted independently, or perhaps in association. Native copper, which occurs in small quantities throughout the Cordilleras, was probably known to them, while stream tin (cassiterite), also of likely occurrence in a limited sense, would furnish a very pure source of tin. The idea that native copper may, itself, contain percentages of tin equivalent to those encountered in these bronzes cannot be entertained.

The fact that the percentage of tin contained in the Inca bronzes is not governed by the use for which they were intended raises the question as to what has governed the percentage of tin in case this was subject to some controlling influence. Joyce's observation that tin is found in greatest quantity in those objects which require it least is particularly interesting, since it suggests that the objects which require the least tin for proper service may require the most tin for some other reason. While I have not found time to search carefully through South American archæological literature for analyses pertaining especially to objects of known character, the present collection offers certain evidence bearing upon this question.

This evidence deals with the casting properties of bronze. As far as the present collection goes, those objects which would require the least tin in service are the more delicate, or ornamental pieces. As already pointed out, the two finest castings, Nos. 2 and 5, contain maximum percentages of tin (13.45 and 9.39, resp.). A few rough experiments indicated that these high percentages of tin yield the best impressions in casting. Bronzes of this character expand in solidifying, whereby the finer details of the mould are registered in the metal, even though subsequent contraction, on cooling to ordinary temperature, determines a total shrinkage effect. Wust (7) determined the value of this expansion (also the total shrinkage) in alloys containing approximately 5, 10, and 20 per cent tin. The percentage expansion was found to be 0.085, 0.122, and 0.01, respectively. Later, Haughton and Turner (8) investigated the same property, using a somewhat different method, and located the maximum expansion at 10 per cent tin. Thus, we see the advantage of choosing alloys containing in the neighborhood of 10 per cent tin for casting purposes. It is also worthy of note that the 10 per cent alloy begins to freeze at a temperature some 50° lower than the 5 per cent alloy, or some 80° lower than pure copper. This means that, as the tin-content increases, alloys from the same initial heat will remain longer in the fluid condition, whereby the casting operation is facilitated, particularly in the case of small objects which tend to chill rapidly.

Modern bronze compositions used in casting objects of art (statuary, etc.) usually contain fair percentages of zinc. This lowers the freezing point, increases fluidity, soundness, and adaptability to hammering, chipping, etc. (lead is also an important addition agent where the latter property is particularly important), decreases cost and produces a pleasing color effect. Thurston (9) specifies several suitable compositions, as follows: (1) Copper—92, Tin—2, Zinc—6; (2) Copper—85, Tin—5, Zinc—11; (3) Copper—65, Tin—3, Zinc—32. The expansion during solidification and total shrinkage are generally favorable in well chosen ternary alloys of this type. Cf. Miller (10).

Zinc occurs only as an incidental impurity in these bronzes and the Inca metallurgists were unable to avail themselves of its useful properties in this connection. Nor were they acquainted with other addition agents (e. g., phosphorus) which, by reducing the heavy, mechanically entangled tin oxide, itself formed during alloying by the reducing action of tin on the copper oxide commonly present in molten copper, slags out the oxide and cleans up the metal. Thus, their castings leave much to be desired by way of soundness and strength.

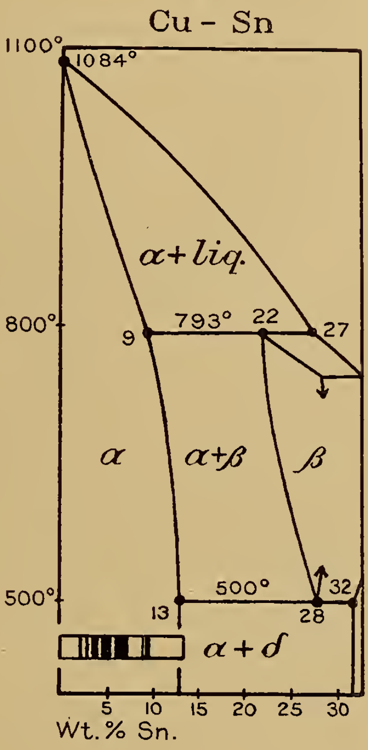
Having accounted for the high percentage of tin in ornamentally cast objects, some attention will now be devoted to the objects which require strength and hardness for general industrial uses. No unusual characteristics were observed in any of these bronzes. They are simple alloys of tin and copper in which the physical properties were modified by the ordinary operations of forging, annealing, and cold-working. There is no evidence that any special heat treatment was adopted in order to facilitate the working of alloys high in tin. The metallographic tests indicate that cast pieces were usually hammered in their original condition and annealed as occasion demanded. Only moderate percentages of tin, preferably below 7 or 8, are safe when free working of the cast metal is a primary consideration. Foote and Buell (11), in a recent examination of three Peruvian bronze axes of uncertain origin, found 12.03, 5.58, and 3.36 per cent tin, respectively. They were unable to cold-work cast metal similar in composition to the first of these axes without first applying a special form of heat-treatment, the significance of which will be pointed out later on (p. 543). The four axes and chisels of the present collection (Nos. 6, 8, 15 and 16) contain from 3.71 to 5.53 per cent tin. Shepherd and Upton (12) have shown that the ductility of cast specimens decreases rapidly beyond 5 per cent tin. The latter alloy gave an ultimate elongation of about 20 per cent, scarcely inferior to that obtained from pure copper, while, at 10 per cent tin, the elongation dropped to half this value. In the words of the author, "by suitable heat treatment, it is possible to vary the ultimate elongation of a bronze containing 90 per cent copper from 10 per cent to 37 per cent without affecting the tensile strength materially."

As will be explained later on, in dealing with the constitution of these alloys, the heat treatment indicated is adapted to bronzes containing the δ constituent and permits the use of higher percentages of tin than any found in the present collection. It is probable that the early Incas, at least, were unfamiliar with refined methods of heat treatment and were compelled to sacrifice the extra hardness and strength obtainable by increasing the tin-content in favor of very free working properties. We would hardly expect the many different objects to show the same composition within narrow limits, since, aside from certain marked variations quite likely to arise in foundry practise which is not subject to analytical control, a greater or lesser degree of softness (measured by the tin-content) would be desired to favor particular requirements in shaping the object. We may add, at this point, that cold-working was invariably depended upon to produce the final stiffness and hardness of an object.

CONSTITUTIONAL RELATIONSHIPS.

From a metallographic standpoint, the most noteworthy conclusion to be drawn from the table of analyses given on p. 531 may be expressed as follows: The full range of concentration covered by this set of alloys corresponds almost exactly with the natural range of stability in the form of so-called alpha solutions of tin in copper. As shown in the equilibrium diagram, fig. 1, the alpha solutions reach from 0 to 13 per cent tin at moderately low temperatures. At higher temperatures, the tin concentration of the saturated alpha solution is lower and amounts to some 9 per cent at 800°. Of the bronzes analyzed, No. 9 (Table I) contains no tin and No. 2 contains the maximum percentage of tin, 13.45. All others lie between these limits. In the lower left hand corner of the diagram, fig. 1, the tin-concentration of each analyzed bronze is indicated by a short vertical line at the corresponding abscissa value. Where the neighboring concentrations differ very little from one another, the lines run together and a general survey of the distribution of these alloys according to tin-content can be gathered from the widths of the bands thus produced. The mean average concentration of all specimens analyzed lies in the neighborhood of 5.75 per cent tin.

Fig. 1.



The abridged diagram, fig. 1, is drawn from data considered most reliable by Guertler (13), who, in his Handbook of Metallography, has critically reviewed the constitutional work of various authors in this field (notably Heycock and Neville and Shepherd and Blough). The more important concentration values, as well as the temperatures of the two horizontals, are written directly into the diagram. Bronzes which, under equilibrium conditions, should be composed exclusively of the alpha constituent immediately after solidification invariably show a zonal structure after ordinary casting and, even when the tin-content is less than 2 per cent, still contain liquid metal when the lowest temperature of alpha crystallization is reached, whereupon solidification is completed in the form of a secondary, or beta constituent.

The minute detail of the transformations which occur in this beta constituent on further cooling cannot be fully described at present. The principal features are, however, well understood and corresponding effects upon the working properties of the metal are not difficult to determine. Probably most of the unstable beta constituent, whose presence in these alloys is due to rapid solidification, is formed in the normal manner by reaction between the residual liquid (after crystallization of alpha) and the neighboring alpha constituent. This would yield a beta of minimum tin-content (22), at least along the line of contact with alpha. The interior of this constituent may be protected from reaction with alpha (by envelopment), in which case, its tin-content will be higher. In view of the facts that the entire beta is small in amount, that it must form within the enveloping alpha, high in copper, and that its corresponding solidus and liquidus concentrations are not far removed from one another, it does not appear that the tin-content at any point, in spite of rapid cooling, can be high enough to permit the separation of anything but alpha (along the line 22-28) on subsequent cooling. During such cooling, the prevailing tendencies are (1) for the enveloping alpha to absorb the beta and to homogenize generally, (2) for the copper-rich beta at the boundaries to separate alpha according to the curve 22-28, and (3) for the peripheral and central portions of the beta to effect a concentration adjustment. However these individual tendencies may operate in conjunction, when the temperature has fallen to 500°, or thereabouts, (4) the residual beta of eutectoid composition will undergo transformation into alpha and delta of distinct eutectoid appearance. Such a structure is represented by fig. 43. The white delta is considerably more abundant than the dotted enclosures (dark) of alpha. The present experiments have shown that this transformation always occurs so as to produce a distinct eutectoid structure in small chill-cast specimens which must have cooled through the transformation temperature at the rate of several degrees per second. It can be suppressed only by active quenching.

Before referring to the effect of this transformation on the malleability of these bronzes, it may be well to add that the recent discovery by Hoyt (14) of an additional transformation point in this portion of the diagram has not been disregarded in seeking to interpret the solidificational phenomena. According to Hoyt's provisional diagram, we should add to the tendencies enumerated above, (3*a*) for the beta to transform into an eutectoid conglomerate of gamma with little alpha when the temperature has fallen to 590°, (3*b*) for the gamma to separate alpha as the temperature falls toward 525°, and (3*c*) for the residual gamma, instead of the residual beta of (4), to develop the final eutectoid of alpha and delta at 525°, instead of at 500°, as previously accepted. All of the numbered statements are representative of tendencies towards change in the direction of equilibrium. The only one which is distinctly realized under the imposed conditions is that (3*c* or 4) which results in the complete replacement of an original beta by an eutectoid conglomerate of alpha and delta. Thus, the intermediate changes are not important in this connection. Hoyt's principal findings are (*a*) that there are two thermal effects below 600° in certain of the copper-rich bronzes and (*b*) that annealing, or slow cooling, between these two temperatures (590° and 525°) develops a new phase, thus far unidentified, between neighboring alpha and beta grains. He considers his results to be of a preliminary nature and only attempts a provisional reconstruction of the diagram.

Bronzes containing the alpha-phase associated with moderate quantities of the beta phase are malleable and may be worked either hot or cold. This is the condition recognized by Foote and Buell (l. c., p. 539) in their treatment of a cast bronze containing 12 per cent tin. The metal was either forged above the transformation temperature or quenched from such a temperature to preserve the beta structure for cold working. By long annealing at a suitable temperature (high enough to promote diffusion and low enough to permit the formation of an alpha solution of high tin concentration—probably 550° is most suitable) the malleability is still further increased, owing to complete absorption of the secondary constituent with formation of a tin-rich alpha bronze whose properties are independent of the mode of cooling, except that overheating will cause beta to separate again and a subsequent slow cooling will again develop the brittle delta. Alloys containing up to 12 or 13 per cent tin may be made very malleable by such treatment. Shepherd and Upton's high values of elongation (l. c., p. 540) are readily explainable upon this basis.

Malleability in the cast condition is highly dependent upon the quantity and distribution of the alpha+delta eutectoid. The principal constituent of this eutectoid, delta, is specifically brittle. A cast bronze with 10 per cent tin will ordinarily contain several per cent of this constituent, but it will not be sufficiently abundant to form a destructive network around the alpha grains and the material may still be worked effectively. With 13 per cent of tin, the metal may usually be worked if handled with care and annealed frequently at low red heat. Such annealing causes gradual absorption of the brittle constituent with continual improvement in malleability. The small object, No. 2, Table I, illustrated in fig. 10, contains a little over 13 per cent tin and was hammered into the shape of a spatula or spoon at one end. In order to test the cold malleability of the metal in its present condition, the end was cut off and a new spatula-tip formed by hammering. This was accomplished without fracture. The grain characteristics of the metal show that light annealing treatment was used to facilitate working. Neither this nor any other specimen examined was quenched after annealing, since no beta structure was observed, while the eutectoid structure was recognized in a number of cases. The unaltered cast structure of this specimen is shown in fig. 41. Aside from the black dendritic cores, a lighter sharply-defined and angular structure-element may be seen within the white matrix of tin-rich alpha. This is the eutectoid constituent which is represented under higher power in fig. 43 on the same page. In quantity, it falls a little short of that required to form a continuous membrane around the casting grains. The structure in this vicinity does not indicate very favorable working properties.

As previously stated, the highly worked bronzes of the collection contain moderate percentages of tin, i. e., less than 10, and, in most cases, only 4 to 6. While such alloys contain a little of the eutectoid constituent in the original cast condition, this is rapidly absorbed on annealing, e. g., in a few minutes at red heat, and the metal is easy to work without any annealing treatment. Finished objects were, as a rule, almost entirely homogeneous and hammer-hardened. It seems fairly obvious that, in the fashioning of these objects, ease of working was placed above other considerations, and the composition of the metal adapted to this requirement.

RECRYSTALLIZATION AND GROWTH OF GRAIN.

Two prominent metallographists, E. Heyn and G. Tammann, have lately dealt with the conditions of recrystallization and growth of grain in overstrained metal. E. Heyn (15) gives curves representing the mean size of grain developed by annealing cold drawn copper wire as a function of the time at four different temperatures, 500°, 700°, 900°, and 1000-1050° C. Experiments were also made with soft iron wire. Owing to the transformations which occur in iron, γ to β at 900° and β to α at 780° C. and their influence upon grain development, particularly that of the former, attention need not be directed to the latter experiments in considering the grain growth of alpha bronzes, which are not subject to transformation. On the basis of the experimental curves obtained and certain fundamental considerations, mainly of surface tension, Heyn develops generalizations relative to the crystallization of cold worked metal.

It is quite evident that, in any particular case, an estimate of the previous treatment to which a given alloy may have been subjected by observation of its grain characteristics requires systematic study of the grain structure developed in a similar alloy under a variety of carefully adjusted conditions. This feature of the present investigation was served by hot working, cold working and annealing under varying conditions a large number (150) of small bronze specimens ranging in composition in three stages from 92 to 96 per cent copper (92, 94, and 96 per cent). It is not the intention in this paper to tabulate the results of these experiments nor to describe them fully. Some pertinent conclusions derived from them will be made use of in the forthcoming description of the individual structures of the ancient bronzes. A number of curves, figs. 2, 3, and 4, representing the development of grain upon annealing (a) chill cast specimens, (b) chill cast and homogenized specimens, and (c) chill cast, homogenized, cold worked and recrystallized (850°) specimens, respectively, all of which had been reduced 25 per cent in area of section by cold hammering, will, however, be shown, together with homogenization curves to be described later. These curves are particularly important in that they show the characteristic annealing proper-

Fig. 2. 96% Cu

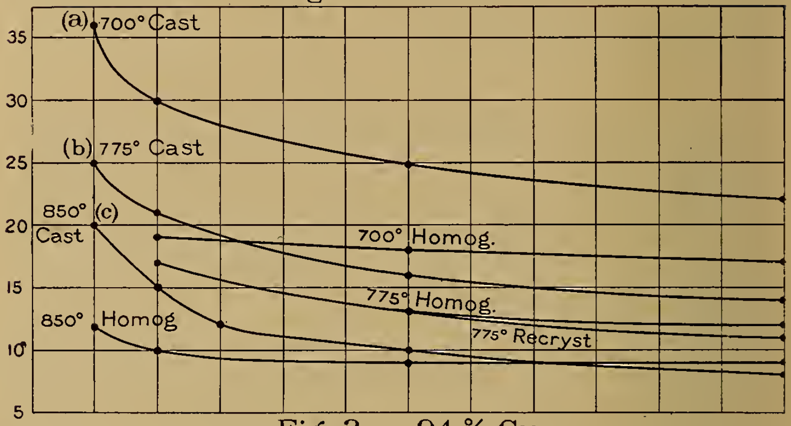


Fig. 3. 94% Cu

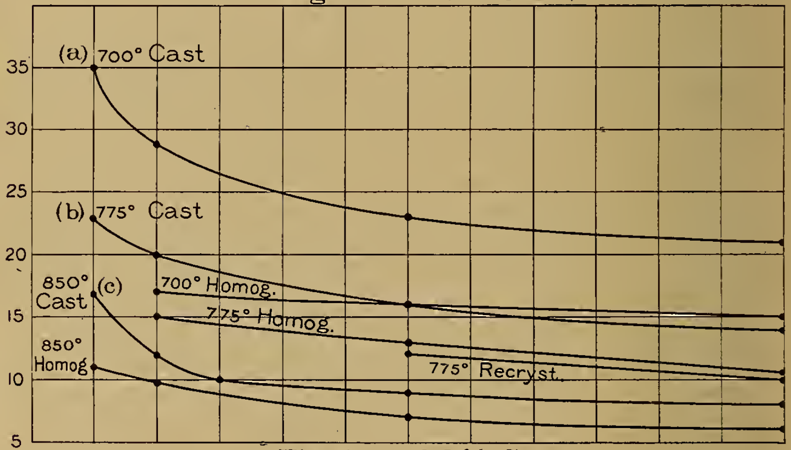
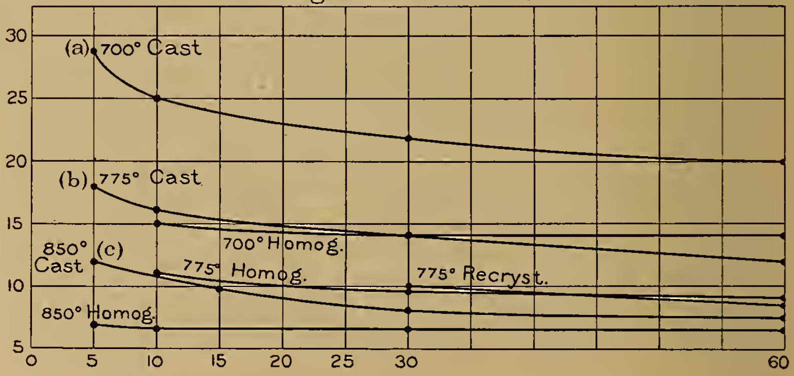


Fig. 4. 92% Cu



Growth of grain on annealing after 25% reduction by cold-working.

ties of the bronzes under present consideration. They may be used to illustrate the generalizations formulated by Heyn and by Tammann. Following the discussion of these curves from such a standpoint, other significant facts will be pointed out.

The curves, a, b, and c, of fig. 2, for example, represent the number of grains counted at a magnification of 72× along a 3½″ line superimposed upon the images of polished and etched sections of cold worked, chill cast bronze containing 96 per cent copper, after different annealing periods at the respective temperatures, 700°, 775° and 850° C.

Heyn, from an experimental standpoint, emphasizes the principle of grain size equilibrium as opposed to ordinary equilibrium in terms of the phase rule. According to this principle, the grains, when brought to a given temperature, coalesce at first rapidly and then more slowly until the mean grain size for this temperature approaches a maximum equilibrium value. This characteristic is distinctly seen in the curves mentioned above. Here, the mean number of grains per linear unit, instead of the mean grain size, is plotted against the time of anneal. Obviously either of these graphical relationships may be used equally well for the present purpose.

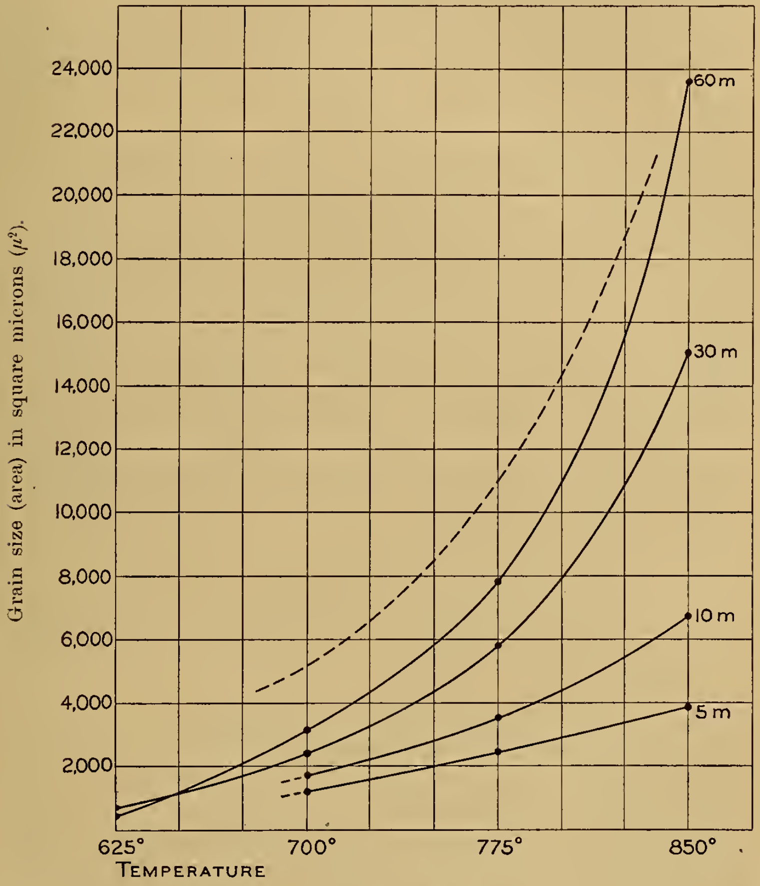
Coalescence represents a natural tendency resulting in decreased surface area and a higher order of stability in accordance with the principles of energetics. Heyn remarks that a certain mobility of the ultimate particles which constitute the grains is necessary in order that coalescence may occur. This mobility increases with the temperature. Hence the grains can grow more effectively as the temperature is raised. At a given temperature, the grains, after sufficiently long exposure, will reach a size corresponding to the mobility for this temperature.

The earliest stages of rearrangement and growth in overstrained metal, which are of great interest from a theoretical standpoint, are not dealt with in these generalizations. As will be seen later, the curves in this region are indeterminate as far as ordinary counting methods are concerned. Phenomena of this order are subject only to qualitative interpretation. The later stages, i. e., those actually observed and recorded in graphical form, are clearly defined and may be characterized at any point. Thus, we see that, within certain limits, a given grain size may be produced by anneal at different temperatures when the time factor is properly adjusted. For example, a count of about 12 grains is obtained in a 5-minute anneal of the cast material containing 92 per cent copper at 850° (fig. 4, curve c) or in a 60-minute anneal of the same material at 775° (fig. 4, curve b). On the other hand, if we assume that the annealing period is neither extremely brief nor excessively prolonged, e. g., occupies from 15 to 60 minutes, the grain size is fairly independent of the time, and will serve to indicate the approximate temperature of anneal. In the present case, the values for 700° range from 24 to 20, those for 775°, from 15 to 12, and those for 850°, from 10 to 7½. It would thus be possible, by measuring the grain size, to estimate whether a cold worked cast bronze containing 92 per cent copper had been annealed at dull red (700°), cherry (900°), or at an intermediate temperature, provided no other complications affecting the growth of grain were present. Similarly, the data plotted in figs. 2 and 3 may be used to interpret the annealing treatment of bronzes containing 96 and 94 per cent copper, respectively.

Tammann (16), in discussing the relationship between temperature and grain size, defines an end condition for each temperature in terms of equilibrium between the tension at the inner surfaces (inter-granular boundaries and intra-granular surfaces of slip, see Theories of Deformation, p. 559) and the rigidity of grain. Thus, the temperature—grain size curves for increasing annealing periods at constant temperature (or for decreasing rates of heating towards a convergent temperature) will lie superposed, the uppermost position (maximum grain size) corresponding to the final condition at which the above equilibrium obtains. Curves of this character, plotted from the data obtained in this investigation, are shown in fig. 5. Annealing periods of 5, 10, 30, and 60 minutes, respectively were used. Since the rate of adjustment between the opposing forces increases with the temperature, the highest value on the uppermost curve more nearly represents a true equilibrium condition for the corresponding temperature than the lower values on this curve. The position of the true equilibrium curve with respect to that of the uppermost curve is accordingly similar to that indicated by the adjacent dotted curve.

The grains counted at 775° and 850° C., even after very brief periods of anneal, in all probability represent completely recrystallized metal in which none of the internal changes due to the original deformation persist. At 625°, however, after a comparatively long anneal (30 m.) there is evidence that some of the grains are fragments of the original distorted grains which would further recrystallize at higher temperatures. The higher temperature ranges of all curves described therefore represent normal coalescence of the natural grains. Experience has shown that the grain size produced by anneal under uniform conditions is very nearly independent of the magnitude of previous deformation, provided this has been considerable. While it is difficult to clearly specify the amount of reduction

Fig. 5.



Growth of grain on annealing after 25% reduction by cold-rolling.
Bronze containing 96% Cu.

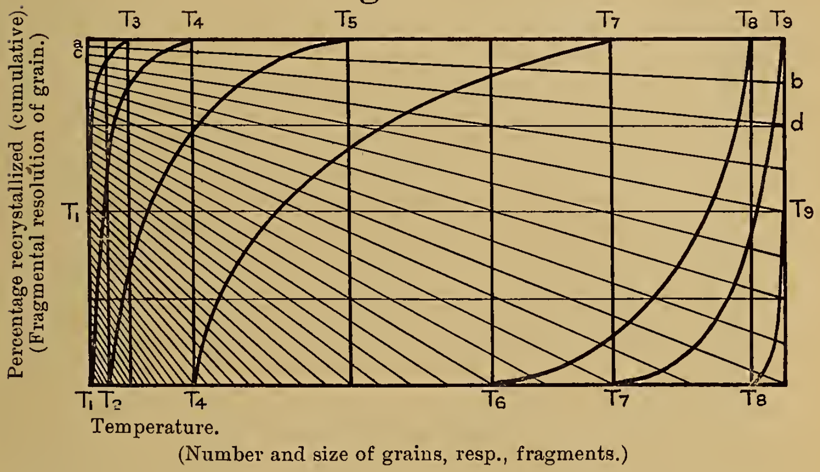
by cold work which is necessary in order to bring about this result, it may be safely asserted that, with this class of material, any reduction above 15 per cent (in area of section) by cold rolling or hammering will suffice to bring about uniform grain characteristics on anneal for moderate periods of time above 700° C. As we pass to lower temperatures of anneal, the visible grain is not in a natural condition throughout, but is constrained, in part, owing to the presence of strained patches or grain fragments which are potentially subject to recrystallization. It is thus evident, that the count cannot be extended to the low temperatures of incipient recrystallization and still retain its original significance. The prolongation of all annealing curves in the direction of their origin must, therefore, be based largely upon theoretical considerations.

A discussion of the lower, as well as the upper ranges of the temperature-grain size curves has been undertaken by Tammann (l. c., p. 548). The principal arguments are as follows: Recrystallization in a conglomerate containing grains artificially reduced by deformation will start at a temperature where the tension at some of the inner surfaces overcomes the rigidity at these points. At other points where the rigidity is greater, recrystallization will not occur until a higher temperature is reached. At any of these equilibrium temperatures, the mean grain size is smaller than would correspond to a natural grain size for the same temperature, owing to increased rigidity. A temperature is ultimately reached where the tensions at the inner surfaces become equal to the rigidity of the mean size of grain for the natural condition. At this point, all evidences of deformation will have disappeared and the curve merges into the natural curve.

I have attempted in the following remarks to give a general outline of recrystallization phenomena with the aid of a provisional diagram, fig. 6, which seems to account for the main facts developed by experiment.

This diagram is based upon the assumption that the mean size of the new grains which form at any given temperature by coalescence of existing grains or by local break-down of internal surfaces within the original strain-hardened grains is determined by the temperature of anneal. Thus, the size of the recrystallized grain will be some function of the annealing temperature and the conglomerate will be composed of recrystallized grains along with unrecrystallized fragments of the mechanically altered grains. Such structures are commonly observed in strained metal which has not been annealed sufficiently to cause complete recrystallization throughout the mass, e. g., fig. 48. The entire field is traversed by a set of lines, ab, cd, etc., which cut any vertical line into a number of segments intended to represent the mean number of recrystallized grains which would normally be counted along a unit length upon the prepared specimen after anneal at the corresponding temperature. A linear relationship is assumed in this construction, but, obviously, any experimentally proven relationship between grain size and annealing temperature may be depicted in similar manner.

Fig. 6.



By cold-working metal of definite grain characteristics, e. g., uniformly recrystallized metal of the mean grain size which would be produced by complete anneal at T_9, the grain structure is broken down, inner surfaces develop and new, latent, grains of a lower order of size and stability are formed. As already stated, these secondary particles cannot be distinguished under the microscope. Etching peculiarities, diminishing contrast, lines of deformation, etc., are, indeed, visible when deformation has been severe, but no direct indication of the size or shape of the ultimate secondary units can be obtained. As far as direct observation goes, these new structure elements are latent only. Upon annealing, they assert a modified individuality wherein mutual readjustment and coalescence cause them to become visible units with definite orientation and the dimensions characteristic of the annealing temperature adopted.

In order that the annealing effect may be felt at a given temperature, it is clear that the mechanical destruction of the original grain must have been sufficiently pronounced to produce fragments inferior in size to the recrystallized grain characteristic of this temperature. Thus, if the T_9 grain previously cited is to recrystallize at T_5 it must have been artificially reduced by deformation to a point where the grain size characteristic of T_5 can develop. In general, the grain fragments produced by deformational processes will vary widely in size, so that certain of them will be able to coalesce below T_5, while others will remain unaffected at this temperature. The particular factors which apply in any given deformational process will combine to determine a curve of Fragmental Resolution of Grain* for this particular process in which the cumulative percentage of fragments below a given size appears as a function of the size of the fragments.

The curve T_4T_7 is a hypothetical curve of this sort and signifies, in the present case, that, by deformation of the original T_9 grain, approximately 65 per cent of the material has been sufficiently reduced (by internal slip) to recrystallize by the time the temperature T_5 is reached. At T_5 then, 65 per cent of the material will have reached the mean grain size characteristic of this temperature, while 35 per cent will remain unannealed.

Little can be said relative to the distribution of the unannealed fragments and the recrystallized grains. In general, the former occur in patches of irregular outline and, when present in comparatively small amount, as in the present case, cannot usually be distinguished from the latter. When present in large amount, however, the patches are large, compared with the size of the recrystallized grains, and often bear evidence of strain. Such a condition is shown in fig. 48. Large patches of metal bearing distinct lines of deformation can be seen along with small recrystallized grains.

The first formation of recrystallized grains usually occurs at the boundaries of the parent grains, since, at such localities, maximum inhomogeneity of the lines of force may be expected and, consequently, maximum fragmental resolution of grain. Initial recrystallization around the primary grains is well

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* I have introduced this phraseology to aid in defining the disintegrating effect of cold-working without regard to the specific nature of the fragments, or particles, formed. Most theories freely admit that sub-granular units possessing some degree of individuality are produced during permanent deformation of the metal.

illustrated by fig. 64, which represents spontaneous recrystallization during hot-working.

As the degree of deformation increases, whether by rolling, drawing, hammering, etc., the curve of fragmental resolution recedes in the direction of maximum resolution, a specific condition for each metal or alloy beyond which further destruction of grain will bring about fracture. Recession in this direction is indicated by the set of curves, T_2T_5, T_1T_4, and T_1T_3. As maximum resolution is approached, the abscissa range covered by the curve becomes narrower, since large fragments give place to smaller ones and the size of the latter cannot be reduced without limit. Ultimately we would reach a condition of uniform resolution into fragments of minimum size. It is improbable that such a condition can be realized without overworking the metal to the point of manifold fracture. Thus, the limiting curve, T_1T_3, is drawn to represent a 50 per cent resolution into fragments of minimum size.

There is, for each metal or alloy, a minimum temperature at which recrystallization will start from a condition of maximum resolution into fragments of minimum size. This temperature is represented by T_1 in the present diagram. One half of the metal deformed according to the curve T_1T_3 would recrystallize at T_1. At the higher temperature, T_3, all of the metal deformed according to the curve, T_1T_3, about 85 per cent of the metal deformed according to T_1T_4, about 35 per cent of the metal deformed according to T_2T_5, but no part of the metal deformed according to T_4T_7 would recrystallize. At T_7, the grain of all four would be identical and would grow uniformly beyond this temperature. These curves all represent severe deformation, in that the percentage of coarse fragments is low compared with the percentage of fine fragments. In the alpha bronzes, such a condition occurs when the reduction by rolling or hammering is carried beyond some 15 or 20 per cent. Above 700°, provided the annealing period is not confined to a short term of minutes, a bronze of definite composition will give uniform grain characteristics whatever the extent of previous reduction beyond the minimum value given. Hence, we may draw certain conclusions relative to heat treatment from these grain characteristics without intimate knowledge of the previous mechanical treatment.

Turning now to the effect of anneal upon metal which has received very light deformational treatment, it appears that the curves of fragmental resolution will here assume a somewhat different form, in that the percentage of coarse fragments will very likely exceed the percentage of fine fragments. This condition is represented by the curves, T_6T_8, T_7T_9, and T_8T_9. Moreover, none of the fragments are likely to be very small and, hence, recrystallization will not start until moderately high temperatures have been attained. Recrystallization according to the curve T_6T_8 starts at T_6, but is confined to small portions of the mass until the temperature rises well towards T_8. At the latter temperature, the entire alloy is recrystallized. According to the curve T_8T_9 the extremely light deformation indicated has left 50 per cent of the original T_9 grain unaltered, while the remainder has been broken down sufficiently to cause recrystallization at T_8, a temperature not greatly below the original annealing temperature. At T_9, the metal has assumed its original grain characteristics and growth will continue normally as the temperature is further elevated. The curve T_7T_9 represents an intermediate condition which may easily be interpreted.

In cases of very light deformation, recrystallization cannot be detected under the microscope, since the recrystallized grains are not greatly inferior in size to the original grains. In this connection, it should be noted that a section through the conglomerate shows large and small grain sections whatever the true size of grain, since a grain may be cut at any point according to its position with regard to the cutting plane. This renders it difficult to detect recrystallization except where the new grains are considerably smaller than the original grains and are sufficiently numerous to form groups of characteristic appearance.

The curves of fragmental resolution are purely hypothetical and only represent in a general way what seem to be predominant characteristics of the ordinary deformational processes. The precise form of any curve will be determined by the nature and intensity of the deformation sustained by the metal.

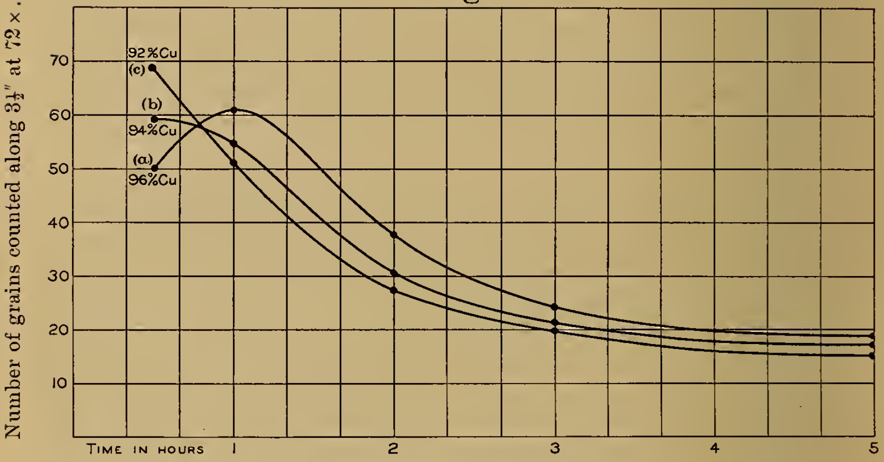
It is clear from the discussion thus far that the form of the curve of fragmental resolution determines the form of curves representing the cumulative percentage of metal recrystallized as a function of the temperature. Without seeking to establish the exact relationship between these curves, it may be assumed that they are substantially identical in form, the former representing an obscure condition and the latter a visible effect. By careful counting under suitably chosen magnification, the approximate form of some of these curves may be determined. The present discussion is intended to convey a rational conception of the connection between deformational and recrystallization phenomena from a qualitative standpoint. As far as the present bronzes go, it is possible to detect incipient recrystallization after severe deformation without inquiring into the details of the treatment effected. Cases of this sort will be pointed out later. Semi-quantitative conclusions bearing upon subsequent growth of grain seem justified from every point of view.

It may be remarked that a diagram of this sort may be drawn to represent the condition developed by anneal during a fixed period of time, or by anneal for the period necessary in order to bring about an equilibrium effect. The latter (ideal) condition was kept in mind throughout the foregoing discussion. The former condition would entail displacement of all recrystallization curves without affecting the general principles involved.

Owing to the difficulty of distinguishing between recrystallized and unrecrystallized units, counting data obtained from partially recrystallized conglomerates are not especially useful or significant. It is possible to obtain at first an increase and, later on, a decrease in the number of visible grains as the period of anneal at constant temperature, or as the temperature for constant period of anneal, increases. This does not signify that the individual grains first disintegrate (contrary to thermodynamical requirements) and later coalesce, but that the original strain-hardened grain fragments (each of which is counted as a single unit) are rapidly developing secondary grains in the early stages of the anneal, while, later, coalescence itself constitutes the predominant factor. Such a condition is represented by the curve lettered (a) in fig. 7. This curve represents the number of distinguishable grains after annealing an alloy containing 96 per cent copper at 625° for periods ranging from one half hour to five hours. Beyond one hour, growth is normal, in that the distinguishable grains increase in size and decrease in number. Between one half hour and one hour, however, the reverse effect is encountered. This reversal evidently takes place earlier in the alloy containing 94 per cent copper, as indicated by the trend of the curve (b) in this vicinity, while, in the alloy containing 92 per cent copper, it must take place at a still earlier stage of recrystallization, since the corresponding curve (c) shows normal growth of grain at the very start. Viewed under the lowest powers, these incipient effects are completely masked by the primary casting structure, e. g., fig. 47, magnified 12×. At ordinary magnifications, both effects may usually be seen, e. g., fig. 91, magnified 72×, while, at the higher magnifications, the finer detail of recrystallization is very apparent, e. g., fig. 48, and fig. 92, both magnified 220×.

A number of the structural changes resulting from thermal and mechanical treatment of a chill-cast bronze containing 94 per cent copper are illustrated by the six photo-micrographs

Fig. 7.



Growth of grain on annealing after 25% reduction by cold-rolling. Annealing temperature 625°.

assembled on p. 603. Fig. 30 shows the cast structure of this bronze magnified 10× after a contrasty etching with ferric chloride. A hole was drilled in the lower part of the specimen as shown. The photo-micrograph represents the upper portion of a transverse section through the small bar and, accordingly, the extension of the grains at right angles to the upper cooling surface can be plainly seen along with the grouping of small grains in the vicinity of this surface. The internal structure of the grains can also be seen. We may call particular attention to the small grain section with striations inclined at an angle of about 45° to the horizontal which is enclosed within a larger grain with vertical striations near the upper right-hand corner of the photo-micrograph. The next figure, numbered

31, represents the same surface, re-polished and etched, after the specimen had received a homogenizing anneal of one and one-half hours at 775°. Here, the contrasts are greater owing to the homogeneous character of the grains. Practically no change in the individuality of the grains has occurred, i. e., there has been no growth of grain. The large individuals of fig. 30 can be recognized in fig. 31 and the small grain previously mentioned has retained its orientation during the heat treatment in spite of the directive influence exerted by the large grain which totally surrounds it. In repolishing the specimen, about 0.003 in. was removed from the surface. Consequently, the small grains, some of which are only a few thousandths of an inch in diameter, do not wholly correspond in the two photo-micrographs. The general effect of re-polishing and etching may be seen by comparing fig. 31 with fig. 32, the latter representing a re-treated surface, which, although subsequently strained, shows how the grain-contours of fig. 31 are altered by a second preparation of the surface.

Any ordinary annealing treatment of cast bronze of this character does not bring about growth of grain. Even the small grains of fig. 30 have not coalesced upon annealing. This may be due to the fact that the grains, while small, are still larger than the normal grains produced by annealing after strain at this temperature. Moreover, the surface conditions in the case of cast grains are less favorable to coalescence than in the case of deformed grains, since, here, a film of impurity may separate the grains, while, after deformation, recrystallization starts within the original grains, at the internal surfaces of slip, where there are no impurities to prevent coalescence or destruction of free surfaces under the influence of surface tension.

Drilling of the specimen has produced a condition of strain which has caused recrystallization upon anneal, as shown in fig. 31. The metal surrounding the aperture now shows the usual fine-grained recrystallized structure in which twins are abundant. A few small twinned grains are also seen at other points upon the surface. This shows that not enough of the surface was removed by polishing after anneal to entirely remove the layer which was strain-hardened in the preceding polishing operation and which recrystallized during the anneal. After the second preparation of the surface (fig. 32), no twinned grains of this sort can be seen.

The small section from which these photo-micrographs were obtained was rectangular with deeply rounded edges at the top. When placed in the vise and strained, the first effects were felt in the lower part of the specimen, while, later, the metal near the top came under the influence of the load. Sufficient pressure was applied to cause permanent deformation of the order shown by the changed dimensions of the aperture in fig. 32. At the lower part of the specimen, deformation has been sufficiently intense to plainly ruffle the surface. Above the aperture, the degree of deformation decreases to a very small value at the top. Upon annealing this specimen, we should, therefore, obtain the characteristics of recrystallization after heavy and light deformation, respectively, upon different portions of the surface. The structure after an anneal of 15 minutes at 775°, is shown in fig. 33. Here, we observe a fine-grained, but rather uniform structure, in the lower left-hand corner of the specimen where deformation was most severe. This structure corresponds to the ordinary effect obtained in annealing metal which has been cold-worked to a point of considerable reduction in area of section. It may be characterized by application of the usual counting methods (cf. figs. 2, 3, 4, with discussion). In other parts of the specimen, only partial refining of the grain has occurred. Near the top, fragments of the original grains may be identified. The small light grain, to which early reference was made, may still be seen in the upper right-hand corner. Below this, a little to the right, a sharp-edged fragment of a large white grain, which reaches to the top in preceding figures, can be distinguished. As already stated,* it is difficult to characterize recrystallization of this sort (after light deformation), since the recrystallized grains cannot be distinguished from the residual fragments. As related to an original cast structure, the fact of recrystallization is clearly apparent, but, as related to a structure which itself shows twins and the general characteristics of recrystallization, even the fact of a subsequent recrystallization is likely to remain obscure. In every case, the grain size and general appearance is highly dependent upon the previous structure. A partially refined grain of this character may be seen in fig. 60. This represents a spot near the broad end of a chisel belonging to the present collection. Large fragments of the casting grains have remained after working and subsequent annealing. The alteration of shape at this point must have been slight and the temperature of anneal high enough to remove cores, viz., bright red heat unless the period was considerably prolonged.

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* See p. 554.

The two ensuing photo-micrographs, figs. 34 and 35, represent further stages in the treatment of this specimen, viz., an anneal of one hour at 775° and one of 15 minutes at 850°, respectively. In both cases, there is very little change in the appearance of the regions which were originally subjected to moderate strain. In the severely strained regions, however, the grains have grown in accordance with the temperature-time requirements previously set forth (see earlier discussion under the present heading).

THEORIES OF DEFORMATION.

The finest grain which can be produced within a metal results from reorganization of the material either by spontaneous transformation according to the principles of heterogeneous equilibrium whereupon new and initially minute crystalline individuals are formed, or by disperse readjustment of the component crystalline particles without change of phase. Since no transformations (phase changes) are involved in the heat treatment of the alpha bronzes, only the latter condition need be considered here.

An extremely fine grain is produced when highly worked metal recrystallizes at the lowest effective temperatures. The growth of grain by coalescence has been described. We have still to account for the condition which causes the initial development of extremely fine grain from a primitive coarse grain. Deformation produces a condition in the primitive grain which causes numerous new grains to develop on annealing. The starting point for each new grain is obviously a fragment of the primitive grain, dislocated, or forced out of alignment with neighboring particles during the process of deformation.

The first changes which occur in an individual grain when it is strained to the point of permanent deformation are well understood, at least from a proximate standpoint; sliding movements occur along planes which correspond to the cleavage planes of minerals so that a set of cleavage elements is formed. These elements do not fall apart, however, but are held in place by adhesive forces of some description. As deformation proceeds, the planes of slip become more numerous and the cleavage elements become smaller. The process may be followed to a certain extent under the microscope by observing the polished surface while under strain, but the precise nature of the movements under severe deformation, leading finally to rupture, cannot be clearly recognized.

Three theories of deformation have lately come into prominence. A brief characterization of each follows:

The Translation Theory, proposed by Tammann, (l. c. (16), p. 56-74), rests upon a purely crystallographic basis. All deformational properties are explained by movements of the above character, in which the original molecular space lattices are maintained; every movement proceeding strictly in accordance with the crystallographic relationships within the primitive grain.

The Displacement Theory (cf. Mollendorff and Czochralski (17)) is based mainly upon ideas of molecular aggregation developed by Lehmann (18) and associates a gradual destruction of the space lattices with the progress of deformation whereby a final condition of "forced homotropy" results, in which the molecules of a primitive grain are not thrown utterly into disorder but are forced into a modified configuration governed by their own mutual attractions and the play of imposed forces.

A Modificational Theory elaborated by Rosenhain (19) from ideas originally advanced by Beilby (20) builds upon the ordinary conception of translation by assuming that thin layers of an amorphous cementing material are formed wherever intercrystalline sliding movements occur. Similar layers are supposed to exist wherever two different grains meet, whether these are recrystallized grains or primary grains of solidification. This theory is especially serviceable in explaining the remarkable adhesive properties of the grains whereby, at ordinary temperature, a fracture normally crosses rather than follows the grain boundaries; while, at elevated temperature, the tendency to pull apart along the boundaries begins to assert itself. These facts are easily explained by attributing suitable properties to the intercrystalline cement, i. e., it is assumed to be rigid and strong at ordinary temperatures, but weakens as the temperature rises. There is no difficulty in proving that a thin, seemingly isotropic, layer of metal is formed at the surface during the operation of fine polishing. This constitutes the experimental basis upon which this theory was developed. Direct proof that such layers are actually amorphous, or indeed, that metal can be transformed into an amorphous modification has not yet been forthcoming. Lehmann believes that these layers are semi-isotropic after the manner of certain liquid crystals.

It is clear that modificational and displacement theories cannot be sharply differentiated without the aid of molecular-theoretical hypotheses which are, themselves, in an imperfect state of development with respect to the ultimate constitution of solid material. Without considering the nature and arrangement of the molecules or molecular aggregates within the individual grains, we may freely observe, apart from any particular theory of deformation, that severe deformation produces numerous subdivisions or dislocations within the original grain which are unstable in form and re-orientate, forming new individuals, on annealing. Relations between surface tension and grain size seem most adaptable in explaining the characteristic alterations of grain on annealing, although Rosenhain (19) dissents from this view and presents his own ideas of grain growth.

MICROGRAPHIC CHARACTERISTICS OF DEFORMATION.

Micrographic methods are not particularly serviceable in detecting the strained condition within a body of metal. The moderate stresses which serve to develop slip bands upon a previously polished surface leave the metal with sensibly unaltered internal structural characteristics. The metal may be strained sufficiently to show a distinct increase in hardness by direct test and to recrystallize on anneal, without visible microscopic alteration of structure. As deformation increases, the normally rectilinear junctions between some of the twinned grains become visibly curved and, later, the etching contrast between neighboring grains decreases along with the appearance of lines of deformation. The latter are straight or curved lines which have etched selectively at the expense of the surrounding material and indicate a profound alteration of the metal. They are typical in appearance and always occur when the deformation has been severe. Their arrangement is not such as to indicate the order of fragmental resolution or destruction of grain by deformation. They merely constitute the principal etching characteristics of highly deformed bronze, brass, and other alloys, and can only be interpreted in a qualitative sense. Ordinarily, the sectional area of a specimen must be reduced at least 15 or 20 per cent by rolling in order to bring about a distinct development of these lines all over the (small) section. The nature of the deformational process cannot be disregarded in seeking to characterize the appearance of the lines or the point at which they first appear. Thus, the same reduction by rolling, drawing, or hammering would not develop precisely the same etching characteristics and, moreover, the mechanical details of a given operation, i. e., the number and intensity of blows, size of hammer face, etc., in hammering; the speed, number of passes, etc., in rolling, would also influence the final result. There are so many of these variables that it is doubtful if the structural effects can ever be sufficiently distinctive to permit a clear interpretation of the contributing factors.

The appearance of these lines of deformation may be seen in fig. 62, which represents the effect of continuous forging from red-heat down to ordinary temperature on an initially coarse recrystallized grain. Partial recrystallization in the form of fine grain has occurred during the early stages of the work at high temperature, but a large number of the original grains have remained and these are traversed by dark markings, mostly curved or wavy. These are positive evidence of the strained condition. In fig. 48, the deformational alteration of a cast structure may be seen under a magnification of 220×. Part of the metal has recrystallized owing to light annealing treatment, but large patches of strain-hardened material may be seen; one in the upper right hand corner and another near the center of the left edge, in which the dark lines of deformation give a crevassed appearance. Other structures which show lines of deformation and, therefore, indicate drastic mechanical treatment subsequent to the last anneal are as follows: figs. 56, 57; figs. 75, 77; figs. 89, 92, and fig. 97.

When the character of the deformational treatment has been such as to produce marked elongation of the specimen, the grains themselves show elongation. This is also an effect which cannot be used in formulating quantitative conclusions, since the elongation of the grains is not strictly proportional to the elongation of the mass but varies with their size and distribution. In an ordinary rolling process, such elongation can usually be distinguished when the reduction in area of section reaches some 25 per cent. The structures shown in fig. 62 and fig. 75 illustrate this condition. It is hardly necessary to remark that annealing removes all evidence of this character.

Diffusional Characteristics.

All cast bronzes differ internally in composition from point to point. Homogenization is effected by annealing treatment. Portevin (21) was able to effect complete homogenization of a bronze containing 95 per cent copper by annealing for a period of three hours at 750°, while a six-hour period at 400°

produced no change in the original casting structure. In a later communication (22), the same author shows a set of photo-micrographs which represent stages in the homogenization of an alloy of the same copper-content at 800°. Homogenization was likewise complete in this case after an annealing period of three hours. The condition of inhomogeneity in cast alloys of the solid solution type is due to incomplete diffusion during the solidification interval and throughout the subsequent period of cooling. It is, therefore, relieved, in accordance with the laws of diffusion, by exposure for an adequate period of time at an effective temperature.

Fick, in 1855 (23), gave a mathematical analysis of diffusional phenomena based upon Fourier's theory of thermal conductivity and fundamentally related to the principle that the rate at which a dissolved substance diffuses into the solvent is proportional to the difference in concentration from point to point. According to Nernst's theory of diffusion (24), osmotic pressure is the driving force which causes the movement of diffusion from regions of high concentration towards those of low concentration. Roberts-Austen (25) showed that fluid metals diffuse in one another according to Fick's law. He also measured the diffusivity of several solid metals in one another at a number of temperatures. Recent progress in the study of constitutional relationships has enabled us to clearly specify those metallic readjustments which are essentially diffusional in nature and not complicated by other molecular changes due to solution, precipitation, chemical reaction, etc. The homogenization of a solid solution is distinctly a process of this sort which, in all probability, proceeds according to Fick's law and is very likely due to osmotic pressure between regions of unlike concentration.

It is thus clear that we must consider primarily the variables of time, temperature and concentration in dealing with this subject. Any experimental result is not clearly defined unless it includes proper specification of all three factors. Accordingly, we cannot make broad use of data similar to that mentioned above (Portevin).

The rapid increase in the rate of diffusion with rise of temperature is a general condition of particular significance in the annealing of such alloys as german silver and cupro-nickel which require very high temperatures for rapid effects. It is well known that ordinary bronzes, brasses, etc., when abnormally inhomogeneous and, therefore, unstable do not spontaneously homogenize at atmospheric temperatures, even after long periods of time. Garland, l. c. (2, second paper), p. 331, describes conditions of this sort affecting Egyptian objects some 3000 years old. Many of the present Peruvian bronzes have likewise retained their initial inhomogeneity through the centuries which must have elapsed since their preparation.

Thorough investigation of the diffusional properties of a group of alloys is, in itself, a task of some magnitude. Since time could not be spared for the complete experimental correlation of time, temperature and concentration in these alloys, it was necessary to make certain approximations and rely upon a moderate amount of suitably selected experimental work.

A cast bronze of the present type is composed of grains, each of which possesses an internal dendritic structure representing its development from the original nucleus by thickening, extending and branching from the primary stem. The average thickness of a stem or branch, as well as the difference in concentration from center to edge, is determined mainly by the rate at which the whole mass solidifies and this is, in turn, determined mainly by the relations between the mass of metal, its temperature at the moment of pouring and the temperature, size, configuration, and heat conductivity of the mold. When the alloy solidifies rapidly, the numerous nuclei, or centers of crystallization, mutually interfere before they can develop to great size; the completed grains will, therefore, be small and their internal structure fine. On the other hand, when cooling is more gradual, fewer nuclei are formed and these grow to greater size and show coarser internal structure. It is true that other factors; supercooling, convection currents, etc., may influence the final structure of a cast alloy. Moreover, we know very little about the actual variation in internal concentration from point to point in specimens produced under different conditions. Gulliver (26) (27), in two papers presented before the Institute of Metals, has dealt quantitatively with the concentration changes which occur during solidification with incomplete adjustment of equilibrium in alloys of the solid solution type, but conditions are highly complicated and it does not seem possible to make any practical use of his deductions in the present case. As a matter of fact, the temperature-time data of homogenization may be fairly well defined on the basis of the average distance between centers of adjacent dendritic branches,* without knowledge as to the average difference in

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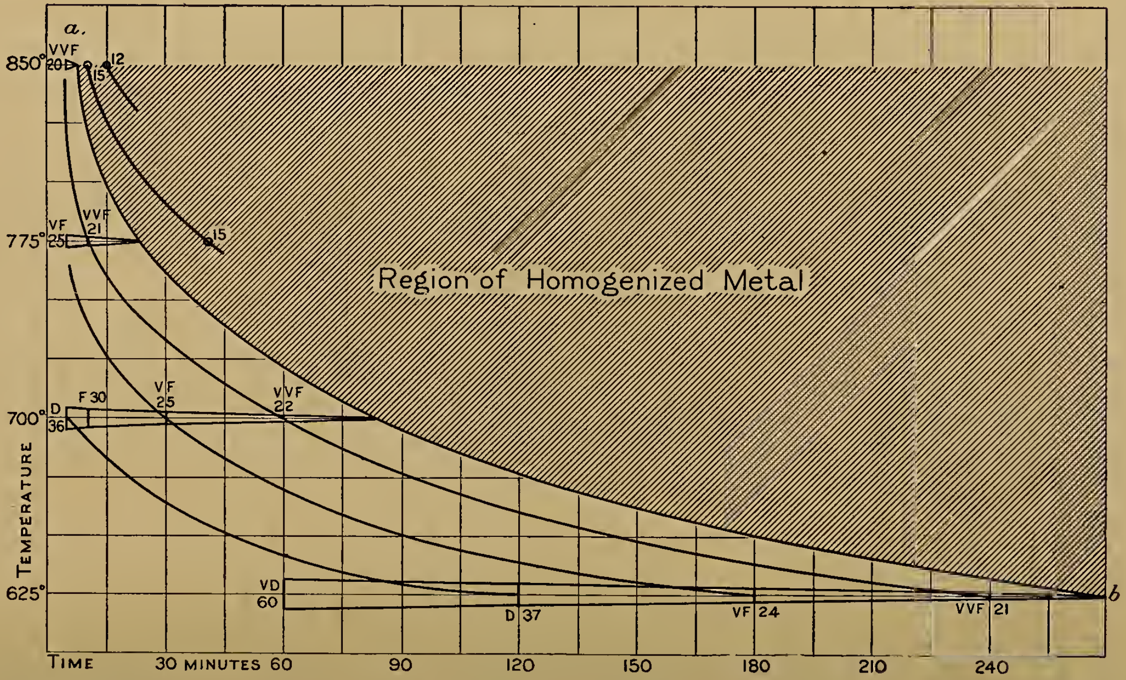
* This gives an approximate measure of the distance which must be covered in the diffusional migration of the molecules.

concentration between such points or the actual rate of cooling which gave rise to the structure in question. It is probable that very similar distribution of material is encountered whenever the average distance between branches (in different specimens) is the same.

The Peruvian bronze objects are, for the most part, small and they were cooled rapidly enough during casting to produce grain characteristics quite comparable with those obtained in the laboratory by chill-casting 60 gram ingots in an open iron mold from a pouring temperature just high enough to hold the metal fluid during the filling of the mold. The laboratory specimens measured 0.015 to 0.04 mm. between branches and a large number of them was used in homogenization experiments with wholly consistent results. In these homogenization experiments, the effect of time and temperature was investigated with respect to this single type of casting structure, which, as already explained, is approximately comparable to some of the structures observed among the Peruvian bronzes. One bronze only (92 per cent copper) of distinctly coarser structure was homogenized at one temperature only (775°) in order to obtain a rough idea of the effect of the third variable on the rate of homogenization at a given temperature.

There is no standard test which may be applied to determine the degree of homogenization after a given treatment. We must rely upon the appearance of the specimen after etching and seek to characterize this in some way. Different etching agents produce different effects and the same etching agent may also produce different effects on the same specimen unless used in wholly similar manner. In all of the experiments, a mixture of ammonia and hydrogen peroxide was used under uniform conditions as far as possible. Six stages in the appearance of a specimen were distinguished and designated as follows: (1) VD, very distinct zones, or cores; (2) D, distinct zones; (3) F, faint zones, clearly visible when the principal detail of the specimen is in focus; (4) VF, very faint zones, visible only as a shadowy effect by manipulating the fine focussing adjustment; (5) VVF, less distinct than the preceding; and (6) H, homogenized, no traces of zones. The final condition does not imply complete homogenization, since these specimens commonly tarnish on long standing in such manner as to indicate some residual inhomogeneity. It does, however, represent a distinct stage approximating the end-point and clearly comparable in different specimens.

Fig. 8.



Homogenization characteristics of small chill-cast bronze ingots containing 96% copper.

Three compositions were investigated, viz., bronzes containing 96, 94, and 92 per cent copper, respectively. Instead of tabulating the large number of experimental results secured, a single typical diagram is shown (fig. 8) and a general summary introduced, as follows:

(1) The time required to homogenize a given alloy at any given temperature is very nearly independent of the composition within this narrow range (92-96 per cent Cu). Alloys containing 96 per cent copper seem to lag a little behind those containing 92 and 94 per cent copper.

(2) Homogenization is complete in very few minutes (5 to 8—with preheating period of 9) at 850°, but requires a period of hours (4-5) at 625°.

(3) The curve (ab, fig. 8) showing the time required for complete homogenization as a function of the temperature indicates a rapidly decreasing temperature-rate of homogenization as lower temperatures are approached. It shows that an infinitely long time would be required for complete homogenization at atmospheric temperatures.

(4) The time required for homogenization at any temperature is substantially the same whether the metal is annealed in the unaltered cast state, or after strain hardening by cold work, i. e., it is unaffected by simultaneous recrystallization of the metal.

(5) As opposed to (4), the grain size produced by recrystallization of strain-hardened metal is highly dependent upon the state of homogenization. By referring to figs. 2, 3, and 4, it may be seen that the two curves showing the number of grains as a function of the time of anneal at given temperature and composition in metal which, in one case, has been cold-worked after casting only, and, in the other case, has been homogenized after casting and then cold-worked (e. g., the curves lettered 700°, cast, and 700°, homogenized, respectively, in fig. 2) lie widely separated from one another. They lie nearer together at high annealing temperatures than at low annealing temperatures, obviously because the cast metal homogenizes in the first few minutes of anneal at the higher temperatures and thus becomes identical (in internal composition) with the metal which had been homogenized previous to cold-working. It does not appear, however, that two respective curves at any temperature would ever meet, whatever the annealing period. Thus, the nature of growth in the early stages of annealing cast metal (of zonal structure) exerts some effect on the final grain size, no matter how prolonged the annealing treatment may be.

It has already been shown that the size of the recrystallized grains in metal of given composition is a function of both the temperature and the time of anneal. Within certain limits, the time factor may be disregarded and an approximate idea of the temperature of anneal deduced from the grain characteristics. Since, the degree of homogenization (as revealed by etching) is also a function of the temperature and time of anneal, it should be possible to obtain a graphical solution for both variables through the medium of the homogenization curve and the curve of grain size. Unfortunately, however, every adjustment of the two variables (temperature and time) to a given degree of homogenization corresponds to about the same grain size, i. e., the two curves are parallel, as far as could be determined by these experiments. This points to some relationship between the phenomena of diffusion (homogenization) and of recrystallization. Pure metals recrystallize after strain-hardening and, since they are of uniform composition throughout, the ordinary process of diffusion cannot occur in them. Molecular movements from one sphere of attraction into another do occur during recrystallization and these are not incomparable with the diffusional migration of molecules, particularly if we argue on the basis of a modification hypothesis, such as that advanced by Rosenhain (l. c., p. 560). Apart from theory, the present experiments indicate that, in the structural reorganization of the metal at elevated temperature, the degree of concentration adjustment is not unrelated to the growth of grain.

With respect to the past history of the Peruvian bronzes, the present experiments show that a structure of the sort represented by fig. 49, which is characterized by a grain count of 33 and a degree of homogenization between D and F, cannot be accurately placed as regards time and temperature of anneal, e. g., it might have been produced by a 5-10 minute period of anneal at 700°, or by a period in the neighborhood of 2 hours at 625°. In any event, it is practically certain that the temperature did not reach bright red in the annealing of this specimen, since, under these conditions, homogenization would have resulted almost immediately and the grain would have grown to much greater size. Broadly speaking, small grains and inhomogeneous structures are characteristic of anneal at the lower temperatures.

For comparison with the chill-cast bronzes of fine texture, a single ingot (92 per cent copper) was cooled at the much slower rate of 150° per minute through its freezing range. This sample measured about 0.1 mm. between branches; approximately three times as much as in the case of the chill-castings. A period of 60 minutes at 775° was required for homogenization. This is about three times as long as the corresponding period for the chill-cast specimens. On the basis of this single experiment, the period of homogenization is roughly proportional to the distance between branches.

The general diffusional characteristics of these alloys are shown in diagrammatic form in fig. 8. Here, the region of homogeneity is shaded and the boundary curve, ab, represents the time-temperature values for complete homogenization. The wedge-shaped outlines represent the gradual disappearance of cores from broad end to point; the width at any marked position corresponding to a given degree of homogenization, D, V, VVF, etc. Along with this lettering, the corresponding grain count is given in figures taken from the original data and otherwise plotted in figs. 2, 3, 4, and 7. Curves, which may be conveniently called *isozonal,* are drawn through the temperature-time points corresponding to the same degree of homogenization (same zonal characteristics). It will be observed that the isozonal grain count is practically constant. For example, the counts along the VVF curve are 20 at 850°, 21 at 775°, 22 at 700°, and 21 at 625°. These experiments do not prove that a definite grain count invariably corresponds to a given degree of homogenization however this may be effected. They merely indicate approximate parallelism of the isozonal curves and the curves of grain size in bronzes of this particular character and treatment. The general question is a broad one, requiring for its solution a wealth of experimental data in which difficult counting problems as well as difficulties in the way of characterizing the degree of homogenization will be encountered.

METALLOGRAPHIC DESCRIPTION OF THE INDIVIDUAL OBJECTS.

The objects are numbered according to Table I.[*] Drawings, diagrams and photo-micrographs are assembled in figs. 9 to 97, pp. 559, *et seq.* The weights of the objects are given in Table I. A brief summary of the structural characteristics and probable treatment of the objects, along with a key to the illustrations and photo-micrographs and designation of the parts examined, is given in Table II.[†] The following list of principal dimensions will serve to fix the scale to which illustrations and drawings have finally been adjusted:

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[*] See p. 531.

[†] See pp. 532 to 535.

Object No. 1, fig. 9. Extreme length, 2 3/4″; extreme width (blade), 2 1/2″.

Object No. 2, fig. 10. Extreme length, 2 3/4″; thickness (stem), 3/32″.

Object No. 3, fig. 11. Extreme length, 12″; diameter of star, 1 1/8″.

Object No. 4, fig. 12. Diameter, 3/4″. Width of aperture, 3/16″.

Object No. 5, fig. 13. Rear of figure to tip of blade, 5 1/8″.

Object No. 6, fig. 14. Extreme length, 5 1/4″; average width, 1 3/16″.

Object No. 7, fig. 15. Extreme length, 3″; rear of head to nose, 9/16″.

Object No. 8, fig. 16. Extreme length, 3″; extreme width (at edge), 2 7/8″.

Object No. 9, fig. 17. Top to bottom, 2 5/8″; length of blade, 3 7/16″.

Object No. 10, fig. 18. Extreme height, 1″; diagonal, 2 3/4″.

Object No. 11, fig. 19. Extreme length, 10 3/4″; Extreme width (at head), 15/16″.

Object No. 12, fig. 21. Diameter of disc, 3 1/8″.

Object No. 13, fig. 22. Extreme length, 2 5/8″; extreme width, 9/16″.

Object No. 14, fig. 20. Top to bottom, 3 1/4″; length of blade, 3 3/8″.

Object No. 15, fig. 23. Top to bottom, 4 1/16″; width at top, 4″.

Object No. 16, fig. 24. Extreme length, 2 3/4″; average width, 1 7/16″.

Object No. 17, fig. 25. Irregular, approximately 3 1/4″ × 2 1/4″.

Object No. 18, fig. 26. Extreme length, 18″; diameter of loop, 1/4″.

Object No. 19, fig. 27. Height, 1 1/4″.

Object No. 20, fig. 28. Length, 17 1/8″; maximum width, 1″.

Object No. 21, fig. 29. Length, 1 7/16″; width, 1/2″.

The photo-micrographs have been reduced one-eighth in the engravings. Stated magnifications refer in all cases to the original photos.

Object No. 1 (cf. Table I).

The knife shown in fig. 9, while similar in general outline to the numerous thin knives of the collection which are represented by figs. 17 and 20, is more substantial and far better executed. From its appearance, the tapered shank might have been hafted or forged into the wedge-shaped blade which is considerably thicker at this point than the shank itself. With this possibility in view, a longitudinal section through the center of the entire blade, shank, and handle was cut for metallographic examination. The outline of this section is shown in fig. 36. The entire surface of the section was explored under the microscope after the usual preparation.

The general structure, characteristic of cast metal, is illustrated by fig. 37, taken from the base of the blade, b, as indicated in the sketch. In this micrograph, the greatest possible hetheogeneity was developed by etching rather deeply with ammonia-hydrogen peroxide and then lightly with ferric chloride-hydrochloric acid. The former reagent does not reveal the black cores but attacks the metal rather uniformly as far as the tin-rich boundaries of the crystallites, showing a raised network of rounded units, each possessing a black border which is not a dark etching but is due to inequality of focus at the edges. The large black cores developed by the ferric chloride represent the copper-rich centers of the grains. Under high power, a small quantity of bluish-gray, or slate-colored, constituent can be seen. This is probably cuprous sulphide, which was invariably found in these bronzes and could be brought into harmony with the analytical figures where sulphur was reported in the analyses. (Cf. description of Object No. 2 for distinction between this constituent and the $\alpha + \delta$ complex.) It is always located within the tin-rich network, described above, as are other comparatively insoluble impurities, mechanically mixed foreign material such as tin oxide, of which indications were obtained in some cases, contraction cavities, etc. Rapidly cooled bronzes, which should normally consist of the α constituent alone, usually show traces of the $\alpha + \delta$ complex even where the tin-content is lower than the present value, 4.82 per cent. This is true in the case of our own chill-cast specimens ranging from 4 to 8 per cent tin and is due to the comparatively slow rate of diffusion as explained earlier. In the present case, however, no traces of any eutectoid structure element could be detected by thorough search with the highest power at our disposal; a one twelfth inch fluorite immersion objective of 1.32 mm. aperture. Such a condition could be produced by slow cooling, but numerous experiments in casting metal at widely different rates of cooling have shown beyond question, that the size attained by the primary dendrites when homogenization in this respect is secured by rather uniformly retarding the rate of cooling throughout the whole casting operation is very much greater than in the present case. The absorption of the $\alpha + \delta$ complex was, therefore, brought about by reheating. Since reheating at bright red heat causes practically complete homogenization in a very few minutes,* it is, on this basis alone, almost certain that the reheating was moderate, i. e., at a low red heat, in order that the present heterogeneity of the specimen may be accounted for. Other reasons for the same conclusion will be stated presently.

The normal site of the $\alpha + \delta$ complex, viz., the centers of the rounded tin-rich excrescences already described, is frequently occupied by very small patches which are faintly distinguishable from the surrounding somewhat lighter material. The particles of cuprous sulphide sometimes appear as kernels within these faint patches. These patches were not observed in any other specimen, either Peruvian or synthetic, and their identity is undetermined. They may represent a stage in the absorption of the $\alpha + \delta$ complex under the influence of the 0.3 per cent of iron which is present in this specimen. The only other specimen containing an appreciable amount of iron, viz., the axe numbered 8, is entirely homogeneous aside from the considerable quantity of sulphide which it contains and cannot be used for comparison in this respect.

The whole knife was undoubtedly cast in one piece. The structure shown in fig. 37 is continuous across the specimen in the region where welding was suspected. Not the least trace of a weld or other type of joint can be found. This structure is, however, modified in the regions, a and c, which are differentiated from b and d in the diagrammatic sketch.

This modification has been effected mainly by cold-working. In these pages, we shall use the term, cold working, with reference to the temperature range within which work upon the metal produces rather permanent distortion visible as lines of deformation within the crystalline grains. The upper limit of this range approximates incipient red heat. That the piece was heated to a temperature of recrystallization either during or after working is shown by the occurrence of small polyhedral grains, largely twinned, as a secondary structure.† It cannot

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* Compare Diffusional Characteristics, pp. 562 to 569.

† The possible occurrence of congenital twins does not invalidate the conclusion drawn above. In common with others (cf. Desch, Metallography, London, 1913, p. 183) we have, in this laboratory, observed twin formation in annealed castings (bronze, german silver, cupro-nickel). In no case, however, was it certain that the metal had been rigorously guarded from strain incidental to handling, etc. Thus far, we have been

be determined by metallographic examination whether this reheating followed cold working of the metal or marked the beginning of the mechanical treatment. It appears most probable that reheating was solely for the purpose of softening the metal to facilitate cold-working. In any event, the temperature employed was relatively low, or the period at red heat was very short as shown by the small size of the grains and the general subversion of this secondary structure to the primary cast structure. Furthermore, even if the working was started hot, the metal was vigorously worked as the temperature fell below red heat and finally left in the cold-worked condition.

It is inconceivable that this piece was repeatedly hammered and reheated to an annealing temperature, as was almost certainly the case with certain other specimens to be described later. Such treatment results in complete refining of the grain with little or no indication of the pre-existing cast structure.

As already suggested, the cast structure was modified mechanically only in the parts a and c. The amount of reduction desired was small and, according to my interpretation of the structures encountered, the shank was constricted towards the center and the blade tapered to a blunt edge through a process of hammering somewhat facilitated by mild reheating.

The complete development of the structure of this specimen was a matter of some difficulty. As already indicated, three distinct, but superimposed, structures were observed; (1) the cast structure, somewhat modified (partially homogenized) by heat treatment, (2) the recrystallized structure, appearing as an incipient refining of the cast structure, and (3) the intergranular deformational detail of (2) due to overstrain during cold working. Since each of these structures possesses its own etching characteristics, it is clear that all of them will not be clearly indicated in a single etching. Thus, etching of the character shown in fig. 37, in which maximum heterogeneity was developed by using ammonia and hydrogen peroxide, followed by ferric chloride and hydrochloric acid, rather effectively masks the (2) type of structure. This is due to the fact that

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unable to produce twin crystals by annealing castings which have been handled with extra care. Vigorous agitation, or stirring, during crystallization does not lead to their formation in bronze. Whatever the facts relative to the genesis of twin crystals in cast metal which has not been intentionally strained, they cannot be mistaken for those developed after vigorous working of the metal. In the former case, the twinning is seen only in isolated regions, while in the latter case, it is everywhere abundant in the case of copper and its alpha solutions.

the recrystallized units are visible only in the cores of the primary dendrites, which are themselves blackened by this treatment. Since the original etchings were made in this manner, it was not at first supposed that the specimen had been reheated. The evidence of deformation was broadly apparent in the threading out of the tin-rich network in a direction perpendicular to the forces applied, particularly where the greatest elongation occurred, viz., towards the apex of the blade. By etching very lightly with an extremely dilute solution of ferric chloride in hydrochloric acid (showing no color) the detail of (2) became apparent within the central portions of the original crystals in the regions a and c, according to the diagrammatic sketch. The reason why the (2) structure cannot be seen in the tin-rich network is plain when we consider that the network is left comparatively bright (unattacked) after etching, i. e., while it is true that a still more inert material within this network, such as cuprous sulphide, can be shown by selective etching of the tin-rich material, the finer detail of the latter is difficult to develop and cannot be developed in a manner continuous with that of the surrounding zones.

That the recrystallized units (2) extend through the tin-rich network constituting the boundaries of the original crystals is, however, apparent by their incompleted character as seen up to this point. The contrast usually shown between differently orientated crystals and different parts of twin crystals cannot be seen with distinctness in this case, since they are located within the cores of the primary crystals which themselves etch and darken selectively as opposed to the tin-rich boundaries. In other words, the secondary (2) structure is more or less masked by the primary cast structure and this fact alone renders very close observation necessary in order to detect the former.

The lines of deformation within the secondary crystals which we have designated as the third superimposed structure can be seen only with the higher powers. Their uniform direction in any given grain, or symmetrical part of a twinned grain, aids in distinguishing the outlines of the grains making up this (2) structure. Obviously, these lines can be seen only in the cold worked portions, a and c, of the specimen.

It may be urged that a description of structures seen under the microscope is unjustifiable without the presentation of photo-micrographs for comparison. Every metallographist is aware that the successful preparation of photo-micrographs at magnifications which are too high to permit the use of prismatic illumination through the objective requires the development of considerable contrast upon the specimen by etching. The difficulties in this direction have already been set forth. In view of the fact that similar but more distinct secondary structures obtained in the study of other objects will be described and illustrated shortly, it has seemed appropriate to forego the introduction of illustrative photo-micrographs here and apply an annealing test to confirm the results of the original examination relative to the distribution of the shaping forces (hammer blows) over the surfaces of the specimen.

A temperature of 700° and a time of one-half hour was adopted for the anneal. The entire longitudinal section was annealed and then explored under the microscope. The general effects obtained in annealing different classes of material have already been discussed.

As may be anticipated from the original examination, the regions b and d of the annealed metal are now nearly homogeneous, showing a grouping of irregularly bounded polygonal grains without twin formation. This proves that the metal in these regions had never been worked. On the other hand, the regions a and c possess a fine-grained structure in which twins are abundant, i. e., the type of structure which would be developed after anneal of cold-worked metal. The two conditions are represented by figs. 39 and 38, respectively. The points at which the photo-micrographs were taken are shown on the diagrammatic sketch. The structures are quite uniform in the areas indicated with rather sharp transition zones. The degree of homogeneity attained in the anneal was strictly comparable with that attained in the anneal of our own material under similar conditions, i. e., only faint shadows accentuated by changing the focus or moving the illuminating prism are seen after anneal for one half hour at 700°. These are due to slight changes in elevation developed by selective etching determined by the varying copper-content at different points. Some of these shadows are faintly seen in fig. 38, particularly across the upper left-hand corner of the photo-micrograph. The fact that this specimen has homogenized to about the same extent as our own cast and hammered specimen proves that any previous heat treatment was not drastic, as previously deduced from other considerations. The size of the recrystallized grains after anneal is also comparable with that obtained under similar conditions with our own specimens. The number of grains counted along 3½″ at 72× for a half hour anneal at 700° was 25. At 775° it was 16, while, in the case of the Peruvian specimen, the value 23 was obtained at a temperature which ran a little above 700°.

In the region d the metal has been slightly overstrained as shown by the somewhat indiscriminate occurrence of a few twin crystals. This may have been caused by our own handling of the piece in the vise, etc. In any event, the effects in question are of little magnitude and are the result of light local deformation. It is inconceivable that the hole at d, which is trapezoidal in section, could have attained its present form by any kind of mechanical treatment after casting. In such case, no spot similar to that shown in fig. 39 at which no recrystallization has occurred, could have been found at the edge of the hole. (See p. 557 for description of the effect produced by annealing around a drilled hole.) We can only conclude that the hole was not bored, or otherwise pierced, but was cast intentionally in the metal.

In this connection, it may be well to state that this was the general practise with the artisans of these objects. Other cases in point will be described later. In every case examined, where no other complications, i. e., indiscriminate mechanical and thermal treatment after casting, have served to mask the original structure, it is evident that these perforations were attained in casting practise rather than by mechanical means. Obviously, the perforation of so tough a metal as copper or bronze in the absence of steel tools was a task incommensurate with the mechanical ingenuity of these Inca craftsmen; requirements in this direction were effectively reduced through their skill in foundry practise.

Judged from the standpoint of soundness, this specimen is the best casting examined. Most of the imperfections occur in the central portion of the thickest part of the metal, at b, but the number of blow-holes, contraction flaws, etc., is small and the piece is of good quality according to present standards. The large number of holes shown in the two photo-micrographs numbered 38 and 39 are in no way typical of the original metal as these structures were obtained after a laboratory anneal and it was thought unwise to sacrifice the specimen by removing enough metal to get entirely below the partially oxidized surface layer.

Object No. 2 (cf. Table I).

The small object shown in fig. 10 was cast in substantially its present form. As in the case of the preceding piece, the casting has been somewhat altered by cold-working. The altered portions are the delicate elongated bird's bill and the lower part of the stem, including the flattened end. As this object was too small to yield satisfactory drillings for analysis, a section was cut from the stem for this purpose. Of the two pieces remaining, the larger, including the bird's figure, was embedded in plaster, ground, and polished for examination. A diagram of this portion is given in fig. 40, along with other figures representing the microstructure. The other piece, flattened at the lower end, was thereupon flattened without fracture at the other end by hammering on an anvil, thus demonstrating the cold malleability of the metal. It was thought desirable to make this test in view of the considerable tin-content of the metal (13.45 per cent) and the comparatively large amount of embrittling $\alpha + \delta$ complex. Cf., in this connection, discussion on pages 543-545. This is shown in fig. 41 as a delicate light-colored constituent within the comparatively broad, white, tin-rich zones which envelop the black cores. Maximum heterogeneity was developed in etching by using a light wash of acidified ferric chloride after the usual treatment with ammonia and hydrogen peroxide.

The casting structure is distinctly predominant all over the surface of the section. The flattened end of the object had, however, received a light annealing treatment between the stages of cold working. This is shown by the occurrence of very fine recrystallized grains, which are abundant in this region, but gradually disappear as we proceed upwards along the stem. Grain characteristics of this sort were developed in the laboratory by annealing at 650°. It is probable that the present object was annealed by thrusting the point into the fire and then withdrawing it, when a dull red color began to creep up the stem.

Tests along the stem showed a scleroscopic hardness of 32-35, while, within the contours of the figure at the head of the object, a hardness value of 14-15 was obtained. Corresponding to these results, the characteristics of deformational treatment were observed only in the stem and at both ends of the object. The effect of working a small casting locally in this manner can be seen on the etched surface without the aid of the microscope. There is a visible difference in the quality of the etching in worked and unaltered regions, respectively. This may be traced to a change in contrast values due to irregular movements of the structural elements during cold working and the appearance of dark-etching lines of deformation within the grains. The photo-micrographs, figs. 44 and 45, afford a comparison between the altered and unaltered casting structure, respectively, after etching with acidified ferric chloride. In the latter figure there is abundant contrast between the small number of grains which are collectively visible under this moderate magnification (72×). An unsound part of the object was purposely chosen for representation in order that characteristic oxidation fissures might be shown without recourse to another micrograph. One of these fissures (black) extends from the left hand edge towards the center near the bottom of the figure. In fig. 44, one grain cannot be distinguished from another and a general effect of elongation in the direction top-bottom is seen in the arrangement of the light constituent ($\alpha + \delta$ complex) lengthwise in this direction. This condition was brought about by cold working. The lines of deformation are not clearly resolved at this magnification. It was not thought desirable to provide another photo-micrograph devoted to this feature, since the same effect is shown in fig. 48, leaving out the small recrystallized units which are not distinguishable in the present object except near the spatula-tip.[†]

The $\alpha + \delta$ complex is the transformation product of a β constituent which was the last material to solidify, and consequently, filled in the interstices between dendritic grains of the primary, α, material. Every change of state in an interstitial material is likely to disturb its alignment with the surrounding material and thus develop cavities. Aside from this, evolution of gas (SO_2, etc.), as a result of diminished solubility or of reaction between dissolved impurities, is likely to occur most freely during the latter stages of solidification when the corresponding concentration values are high. As a matter of fact, cavities could be seen in almost every patch of complex when examined under high power. Very small ones would be indistinguishable from the minute, dark-etching particles of α. The rounded black spot in the uppermost branch of the large patch shown in fig. 43 (300×) is one of these cavities. A number of similar black spots may be seen among the numerous patches of complex shown under low power in fig. 41.

Oxidation of the finely divided α of the $\alpha + \delta$ complex starts at the surface of the casting and its inward creep is facilitated

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[*] See p. 561.

[†] See p. 562.

by the prevailing porosity. The massive grains of α are attacked only superficially, resulting in the formation of a thin patina. Consequently, the very considerable oxidation which has affected only those objects which contain a comparatively large amount of the complex (this specimen and the one numbered 5) is confined to this structure element and its path may be plainly followed under the microscope. Reference has been made above to the oxidation cavities of fig. 45. In this photomicrograph, neighboring patches of unaltered complex are visible and the general similarity in appearance leaves no doubt as to the nature of the material which originally filled the dark cavities. In fig. 42, an altered patch is shown under higher power (300×). This may be compared with the light patch shown in fig. 43. Small bright particles of residual δ are seen. A number of stages in the process of alteration were observed. The α constituent is attacked first, but oxidation ultimately extends throughout the complex.

The sulphide constituent, undoubtedly Cu_2S, is unattacked by any of the etching agents used, but, while it is left bright, it may be distinguished from the silvery δ by its bluish-gray or slaty color. The distinction may be made without difficulty in photo-micrograph, fig. 43. Here, the sulphide constituent is a little darker than the neighboring δ. Three rather large rounded units are seen closely grouped at the extremity of the thin projecting branch of the main patch of complex and one unit half-way down this branch. In fig. 42, where the complex has been altered so as to appear dark, the sulphide constituent, in the shape of three units somewhat larger than those of fig. 43 (two, very close to one another above the center at the left, and one, below the center at the right) is particularly prominent by reason of enhanced contrast. The amount of sulphide in this object is inconsiderable and sulphur was not reported in the analysis. It always occurs in association with the complex, usually as a neighboring constituent, but, sometimes, completely enveloped by the latter. Accordingly, cuprous sulphide is appreciably soluble in the β liquid solution and most of it separates when this solution begins to crystallize.

Object No. 3 (cf. Table I).

This is a symmetrical and well-shaped pointed object about 12″ long, of the type commonly used to fasten the outer garment. As may be seen in the illustration, fig. 11, it has a six-pointed star-shaped head and tapers gradually to the rather blunt point. In order to study the structure of the metal in the head, a cut was carried from the knob at the top along the principal axis of the pin well into its shank. The section was then detached by a transverse cut. The location and surface configuration of this section is shown in the diagram, fig. 46. A short section was also taken out of the lower part of the shank, as indicated. A fair idea of the structural characteristics of the entire object should be obtainable by examination of these two pieces.

The lower part of the object bears evidence of far more effective annealing treatment than was encountered in the case of the two preceding specimens. Here, the recrystallized structure is predominant and only a trace of the original casting structure remains in the form of shadowy cores, as shown in fig. 49. As pointed out in the section on Diffusional Characteristics, the degree of homogenization and the grain size correspond so that a particular combination of the two may be produced by annealing for a short time at a high temperature or for a longer time at a lower temperature. In this particular case, the grain count of 33 and the degree of homogenization, D-F might be produced, according to the diagram, fig. 8 which applies here, by a short annealing period of minutes at 700° or a period of several hours at 625°. It is unlikely that the Inca metallurgists would have resorted to a period of hours in which to soften the metal when a brief period at higher temperature would have been equally effective. They desired to soften the lower part of the object so that further extension could be effected. Very likely they annealed it more than once (after corresponding working stages), but in such manner that the temperature attained in the upper part, near the head, fell considerably short of that attained in the lower part. This is beyond question, since the upper part has just started to recrystallize in the locality marked by a black dot in fig. 46, and structurally represented by fig. 48, while, higher up, beyond the dotted region of fig. 46, no recrystallization has occurred and the original casting grains are still preserved in a severely deformed condition.

All the evidence indicates that this object was annealed with decreasing intensity from the point towards the head, i. e., by thrusting it part way into the fire. While we cannot deduce the exact temperature-range and time of anneal from the structure at any point, it is practically certain that the temperature of the lower portion did not greatly exceed 700°, since a very

[*] See section on Diffusional Characteristics.

short exposure at a materially higher temperature would have produced a distinctly coarser grain. It is also probable that the temperature of this portion was not greatly inferior to 700°, since a drop of 50 or 75° would necessitate a very lengthy period of annealing in order to produce the present characteristics. It is the writer's opinion that, in the annealing of this pin, a moderate red heat was developed near the point with gradual fall to black heat at the head.

Deformational characteristics abound all over the object. Fig. 48 has already been cited in this connection (p. 578). This is an interesting photo-micrograph as it shows (1) a primary zonal structure, e. g., dark-etching centers as in the lower left hand corner, (2) portions of the casting grains altered by severe deformation, and (3) small but clearly distinguishable recrystallized grains. In fig. 47, magnification 12×, the field of view is carried from the lower part of the head-section (vicinity of fig. 48) as far as the massive part of the head. It reveals a casting structure of normal appearance. Alteration of the order shown in fig. 48 is not indicated under this low power. Exploration of the upper part of the head-section under high power has shown that the star-branches and the knob at the top preserve the general shape of the original casting but were brought to a smooth finish by hammering or some deeper-seated process than that of simple abrasion. The surface characteristics of the shank were reproduced in the laboratory by hammering on the anvil with a broad-faced hammer.

Object No. 4 (cf. Table I).

This is one of the several very nearly spherical objects included in the collection, all of them provided with a point of attachment in the shape of a pin sunk into a hemispherical cavity. They may have been used as plumb-bobs, sounding, or fishing weights, etc. This specimen is illustrated in fig. 12, and a diagram of the section examined is given in fig. 50. The cut along this plane traversed the pin centrally from end to end and divided the object symmetrically into two parts.

The finer structural detail of the object is of secondary importance. It is particularly desirable to illustrate the two types of crystallization encountered, one in the body of the object and the other in the pin, as well as the form of transition from one to the other. This is best effected through the medium of photo-micrographs at low power prepared after a contrasty etching with acidified ferric chloride. One of these, fig. 51, shows the structure of the pin and the change of structure which occurs on passing through the pin into the adjacent metal, while the other, fig. 52, shows the structure at the base of the hemispherical depression just below the pin. The latter is typical of the crystallization at large.

The present alloy contains a low percentage of tin (2.11) and a high enough percentage of silver (0.81) to give it a ternary aspect. Without special knowledge of the ternary relationships involved, it is not possible to fix the identity of a bright secondary constituent which was observed in the location commonly held by the $\alpha \times \delta$ complex. This constituent is not of eutectoid appearance, nor may it be positively identified as the sulphide constituent usually found in these bronzes, although similar in many respects. It is barely distinguishable between the lobes of some of the grains in fig. 52 (in the form of bright points). The somewhat deeper etching in fig. 51 has obscured this structural feature at the present magnification. It may be observed, in this connection, that sulphur was not reported in the analysis of the present object (cf. Table I). For present purposes it is not essential that the nature of this structure-element be ascertained and no further experiments were devoted to this question. Far more important is the fact that it occurs with well-marked characteristics both in the pin and in the body of the object, whereby we may affirm that both parts are composed of the same metal.

While the structure of the pin is distinctly different from the structure of the adjacent metal, in that twinned elements abound in the former but are entirely lacking in the latter, the transition from one to the other is gradual and continuous; no mechanical union, welded or soldered joint, or duplex casting could furnish the degree of continuity revealed in fig. 51. There is no doubt that the pin was cast along with the rest of the metal, i. e., the object was completely formed in one casting operation. In the tabulated summary of metallographic results, it is suggested that congenital twinning may have occurred in this object. The comparatively small volume of metal comprising the pin probably solidified first and realized an appreciable fraction of its total shrinkage by the time it was gripped by the adjacent metal. Subsequent contraction of the latter might then have overstrained it at a temperature favorable to recrystallization. This is purely a provisional explanation. The facts and conditions pertaining to congenital twinning are not well enough understood at present to permit any clear identification of such phenomena. It is possible that the rough edges of the pin as cast were dressed in such manner as to overstrain the metal. In such case, recrystallization with twin formation would have occurred on annealing. There is, however, no evidence that the object has ever been annealed. Moreover, a dressing of this sort would almost certainly produce corresponding alteration of the adjacent metal and probably of the metal below the pin. There is, however, no recrystallization in these parts. In conclusion, it must be admitted that no clear explanation of the segregated twin-formation which has occurred in this object can be offered.

Object No. 5 (cf. Table I).

This object is the finest example of casting practise furnished by the entire collection. As may be seen in fig. 13, it represents a knife of some sort surmounted by an ornamental group comprising a prostrate fisher-boy with line and fish. The metallographic description of this specimen may be made very brief. A section through the body and head of the figure shows a characteristic casting structure. The outline of this section is given in fig. 53, and the corresponding photo-micrograph in fig. 54. Corresponding to the high tin-content of the object some patches of $\alpha + \delta$ complex may be seen within the tin-rich matrix even under the moderate magnification chosen for this micrograph, e. g., a sinuous patch just beyond the right-hand margin a little above the center. Most of this constituent, however, has been destroyed by oxidation. The black patches represent oxidation cavities. They are very numerous and the highly oxidized condition of the specimen was apparent from the crumbly character of the drillings, the friability of the metal, and the nature of the analytical results (total metallics 97.64 per cent, cf. Table I). No direct determination of oxygen was made.

It seemed unwise to mutilate this unusual object except on one side only. Consequently, a section was not taken through the blade. However, some parts of it were polished as well as possible by manipulating the whole object on the polishing discs. The subsequent examination showed that the blade had been shaped after casting but without sufficiently drastic annealing treatment to remove the casting cores or even the patches of complex. Very fine-grained recrystallization had occurred and prominent deformational characteristics were observed. The structure in this part of the object is similar to that illustrated in fig. 92 (cf. description of Object No. 16). This specimen, in common with many others, seems to have been cast with a light body of outlying metal corresponding to the blade and from which the latter was wrought without very pronounced change of shape and without the necessity of drastic annealing. Probably this part was momentarily brought to red heat after partial working.

Object No. 6 (cf. Table I).

The chisel shown in fig. 14 is one of the most interesting pieces examined, since it is the only one in which distinct evidence of hot working was obtained. This evidence is confined to the blade of the chisel and leads to the conclusion that this part was formed by bringing the object to bright red heat (neighborhood of 850°) and hammering both in this condition and during the fall of temperature to a point well below that of redness. A large number of forging experiments were undertaken in order to acquire some familiarity with the structures produced under different conditions. In these experiments, the following factors were varied within reasonable limits; temperature, previous condition with regard to grain size, degree of homogenization, etc., number and intensity of blows, temperature range of hammering, conditions of intermittent working with reheating, and period of rest at the forging temperature. Presentation of these results is beyond the scope of this paper. Only the structures found in this object and duplicate structures obtained in the laboratory by applying the appropriate treatment will be shown.

The structure shown in fig. 58 corresponds to a scleroscopic hardness of 14. The spot at which this photo-micrograph was taken is indicated on the diagram at the left, fig. 55, and corresponds to a distance of about one inch from the extreme edge. A little further on, the hardness drops a few points and averages 9-10 along the main body of the object, showing that the metal is in a soft condition. It will be noted that the grains shown in fig. 58 are abundantly twinned, of rather uniform appearance, and equiaxed. No lines of deformation are visible and it is evident that the metal has recrystallized after permanent distortion at some stage of its existence. Whether the deformation was effected by cold-working or by forging at a high temperature cannot be foretold from this structure alone, since, in either case, the metal must have been left at rest at high temperature after working (ordinary annealing after cold-working or a sojourn at the forging temperature while work was confined to another portion) and the same ultimate grain characteristics are developed in either case. The observed grain count of 13 indicates that this temperature was in the neighborhood of 800.°

The condition of the metal near the edge, however, throws much light upon this question. Passing towards the edge from the point at which photo-micrograph, fig. 58, was taken, the grains very soon begin to show lines of deformation and elongation in the direction of the principal axis. Moreover, smaller recrystallized units begin to appear among the distorted parent grains. This structure is shown in fig. 57, after ordinary etching with ammonia and hydrogen peroxide. (This method of etching permits a clearer photographic reproduction of the finer detail than is ordinarily the case with ferric chloride, which gives pleasing contrasty effects with coarser structures, as in fig. 58.) As the edge of the chisel is approached, fig. 56, the grains become finer, the lines of deformation more abundant, and the elongation more pronounced. In other words, the proportion of strain-hardened metal is greater. This was tested by the scleroscope which gave average values of 15, one half inch from the edge; 24, five sixteenths of an inch from the edge; and 30, three sixteenths of an inch from the edge.

The structures shown in figs. 56 and 57 are characteristic of hot-working at a temperature in the vicinity of 800° with continuation of working as the temperature falls to a low value. As a grain is deformed under the blow of the hammer, it spontaneously recrystallizes at those points where the strain was greatest. In tapering an object, as in the present case, deformation is greatest in the thinner portions, hence there will be more points of recrystallization in these regions and more abundant lines of deformation if the cold-work is confined largely to these regions, as is likely to be the case. The same succession of structures was obtained in the laboratory by hot- and cold-working a piece of metal from the shank of the chisel to a tapered edge.* The structure at one point is shown in fig. 62, with diagram of position at the left, fig. 61. It will be observed that this structure corresponds closely with that shown in fig. 57. Cold-working has been somewhat more

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* Metal from this chisel was used in order to obtain the best possible comparison. Precisely the same effects were obtained with alloys prepared in the laboratory.

severe, as shown by the more prominent lines of deformation (wavy lines giving a crevassed appearance to the grain-fragments). If the metal is worked only while the temperature is at red heat and thereupon allowed to cool undisturbed (rapidly), the same grain characteristics are observed except for the absence of lines of deformation. The effect of this treatment is shown in fig. 64, with diagram of position at the left, fig. 63. In fig. 14, it is observed that the edge of the chisel has been turned in use. This condition must have influenced the structure somewhat at the extreme edge. Such alteration does not, however, extend far from the edge. For example, the position represented by fig. 56, is near enough the edge to show a fissure where the metal has split in use. Yet there seems to be no interference with the normal elongation of the grains as prescribed by the original process of hammering from the sides.

It seems probable that more than one heat was used in forging the blade of this chisel. This would explain the uniform coarse grain of fig. 58, representing the condition of the metal where the taper begins, and the fact that the grain is more highly refined in this vicinity than along the body of the object. According to this interpretation, the whole blade was partly forged to shape in the first heat. On reheating to the forging temperature, coarse grain developed and was subsequently unaltered in this portion of the piece, but was altered, as described above, further along towards the edge.

The structure at the head of the chisel is shown in fig. 60, with diagram of position at the left, fig. 59. This represents the general structure in the body. It clearly indicates that the object preserves approximately the shape of the original casting, since large unrecrystallized fragments of the original grains may still be seen. Owing to the use of high temperatures in forging or annealing no traces of the internal grain structure remain. The small dark spots represent particles of sulphide. Normally a large part of this material separates out between the casting grains, and in this photo-micrograph some of it may still be seen in the grain boundaries. In completely recrystallized structures the sulphide is distributed without relation to the grain boundaries, e. g., fig. 69. The present structure may have been developed by reheating after hot-working or by annealing after cold-working. Since the blade was almost certainly hot-worked, the former interpretation seems more reasonable.

Object No. 7 (cf. Table I).

That the Inca craftsmen were able to show considerable variety in their methods of shaping these small implements became evident on examination of the small knife with ornamental llama head at the extremity of the handle shown in fig. 15. A number of cast structures, some of them unaltered, some altered by cold-working with annealing, and one altered by hot-working, have been described. The present specimen is of a duplex character, in that two distinct varieties of metal were used in its construction. A vertical section sawed through the center of the ornamental head and part of the shank is shown diagrammatically in fig. 65. This diagram was made from the polished, but unetched section, in which the boundary line between the two kinds of metal was plainly apparent owing to a difference of color and sharp discontinuity at the junction. These facts are very well represented in the photo-micrograph, fig. 66, taken at a magnification of 12× from the unetched section. The color difference is shown by the well developed contrast between the two alloys, further accentuated by a dendritic structural resolution of the other alloy, which is mainly due to a difference of hardness, and, consequently, of elevation between the central cores and boundary zones of the branched crystallites. The presence of numerous pits, or blow-holes, located in the boundary zones where final solidification occurred has also contributed to this effect. It is not necessary to resort to etching, or to a higher magnification, in order to demonstrate that the metal composing the main portion of the ornamental head is now in the condition originally produced by casting. This is evident from the casting structure revealed in fig. 66.

When drillings were taken from this specimen for analysis, its duplex character was not recognized and only the lower part of the handle and the upper part of the blade were sampled. This is the metal which projects up into the head and is of a reddish tint, corresponding to its low tin-content of 3 per cent. It is evident from the white color of the surrounding metal that this contains a much higher percentage of tin.

Fig. 67 represents the structure of the metal composing the shank and blade of the knife. It is entirely homogeneous and has been annealed after deformation. The grain count of 18 indicates that a temperature of 700-800° was reached in annealing.

Since the outside metal possesses a casting structure, it is natural to conclude that it was cast in place around a core of the metal which forms the shank and blade. It is seen from the two sections, a and b, of fig. 65, which are parallel and about one sixteenth of an inch apart, that the central core bends over at the top and develops an appendage which is also embedded in the second metal. Such a complicated fitting could only be obtained by flowing the outside metal around the inner piece. The general shape and appearance of the aperture indicates that it was left in casting. Naturally the details of this interesting casting practise cannot be described.

Object No. 8 (cf. Table I).

Only a single section was cut from the axe illustrated in fig. 16. The position of this is shown in fig. 68, and the structure well under the skin in fig. 69 of the same plate. The most striking feature of this photo-micrograph is furnished by the large amount of cuprous sulphide which is normally bluish-gray in appearance but has fallen away in places, as a result of grinding and polishing, leaving black pits. According to the analytical results given in Table I, there is 0.44 per cent of sulphur in this specimen, a value which corresponds to about 2.2 per cent of cuprous sulphide. By comparing the present photo-micrograph with the preceding one, fig. 67, which illustrates the structure of the copper-rich metal in the knife just described, a good idea of the value of the microscope in estimating the sulphur-content of a bronze may be obtained. A trace of sulphur was indicated in the qualitative examination of this knife. It is plainly evident in fig. 67; less abundant and structurally finer than in fig. 69, but of the same general characteristics.

In spite of the large amount of sulphide contained in this object, its cold-working properties are retained to a surprising degree. A piece measuring 9 × 7 × 16 mm. was cut from the head of the axe and cold-rolled in several passes to a round rod 4 mm. in diameter and 35 mm. long. Further extension could not be obtained without fracture. As a result of this treatment, the particles of sulphide have adapted their own shape to the changing form of the bronze matrix and now appear elongated without evidence of fracture. (They do not show cracks or fissures on the polished surface.) The photo-micrograph, fig. 87, which represents this condition, was taken after momentary annealing at a full red heat.

The coarse grain of fig. 69 indicates that the object has been thoroughly annealed at a temperature not lower than

800°. The observed grain count of 10 can be duplicated in ordinary bronze of approximately the same tin-content by annealing for a period of some fifteen minutes at 850°, while, at 775°, more than an hour is required. Separated impurities, such as cuprous sulphide in the present case, as a rule interfere with coalescence and retard growth of grain. The large quantity of sulphide shown in fig. 69 would probably raise the normal annealing temperature corresponding to the grain represented. The object has not been worked severely enough to sensibly alter the rounded character of the sulphide particles. The original casting was, therefore, similar in size and shape to the finished object. Corresponding to the thorough annealing treatment adopted, the metal is completely homogenized.

Object No. 9 (cf. Table I).

The knife illustrated in fig. 17 is the only one of the analyzed objects which contains no metal alloyed to the copper base. Cuprous oxide ordinarily occurs in copper and this is the case with the present object. The amount of oxide is considerably greater than that encountered in ordinary commercial copper of the present day, in which reduction of the oxide has been effected by the operation of poling, leaving some 0.3–0.6 per cent of oxide in the tough pitch metal. Photo-micrograph, fig. 72, represents the structure of the metal in the shank just where it joins the blade. Cf. diagram of position, fig. 70, *a*. Here, the casting structure may be recognized in the dark areas of dotted appearance which represent the eutectic of copper and cuprous oxide somewhat distorted out of the original casting position by mechanical treatment. According to a rough estimate, the eutectic constituent occupies about one third of the total area of the photo-micrograph. Since this constituent itself contains all of the cuprous oxide in the proportion of three and one half per cent of oxide to ninety six and one half per cent of copper, there are about one and two tenths per cent of oxide in the alloy ($0.33\frac{1}{3} \times 0.03\frac{1}{2} \times 100$). This is twice the quantity previously mentioned.

That the material of the shank has been moderately worked and then annealed is evident from the moderate extension of the eutectic areas and the recrystallization with twin lamellae shown in fig. 72. The material of the blade has been worked much more extensively, as would be expected from its thinness (minimum, 0.040″). This is clearly shown by the fact that each group of oxide particles, originally scattered through the copper matrix so as to constitute an equiaxed patch of eutectic, has been dragged out into a continuous train giving the appearance of a dotted line in the photo-micrograph, fig. 71; diagram of position, fig. 70, *b*. The annealing characteristics of copper containing oxygen in this form have not been sufficiently defined to justify a prediction as to the probable annealing temperature.

The direction of elongation is shown in the diagram, fig. 70, *a* and *b*. It is the same in both shank and blade, viz., from handle to blade and from base of blade to edge. Moreover, in the flare of the blade, the metal decreases in thickness from the center both towards the edge and the base of the blade. These facts suggest that the knife was made from a flat T-shaped casting in which the stem was nearly as long as the finished shank and handle and the cross-piece practically equal in length to the finished blade from tip to tip.

Object No. 10 (cf. Table I).

As may be seen from the illustration, fig. 18, this object represents a broken axe blade. The axe previously described (Object No. 8) is also broken. Baessler (28) states that some of the objects in his collection were mutilated in a manner which could not have occurred through use. He believes that they were intentionally mutilated before burial with the owner. The present fragment shows a comparatively coarse recrystallized grain with a small amount of tin-rich material which has not passed into solution during the annealing treatment. This structure is shown in fig. 74, diagram of position, fig. 73. There are no indications of hot-working on the section examined. If hot-worked at all, the piece received a subsequent anneal at bright red heat whereby the characteristics of forging were replaced by comparatively uniform coarse grain.

The structure very near the edge is notable in that it shows severe deformation of a character which could only result from an upsetting operation; not from the ordinary method of shaping the edge by lateral application of force (hammering or rolling along the sides). Fig. 75 represents this feature. This photo-micrograph is mounted to conform with the directional requirements of the diagram, fig. 73. Lines of deformation and elongation of the grains are plainly evident. In its present condition the blade is nicely rounded to a blunt edge bearing scratches which indicate that it was finished on a stone or in a similar manner. It appears reasonable to conclude that this implement was used in heavy work, perhaps upon stone, whereby the edge suffered severely and was appropriately dressed from time to time.

Object No. 11 (cf. Table I).

Only the flattened head of the cloak pin illustrated in fig. 19 was examined. A number of hardness tests were made on different parts of the surface after removing the outer skin. Scleroscopic numbers varying from 14 to 18 were obtained. This indicates that the metal was finished hard and the recrystallized structure shown in the photo-micrograph, fig. 77, supplies additional information to the effect that intermediate annealing treatment was applied in flattening the head. Some undissolved tin-rich material (light centers with broad black boundaries due to inequality of focus) is present. Abundant lines of deformation, corresponding to the hard finish, may be seen.

The head of this object bears an aperture just above the union with the shank, as shown in the diagram, fig. 76. This aperture almost certainly existed before the head was flattened, since it is now asymmetrically conical in shape, a condition which may easily be duplicated by hammering over one face of an ordinary cylindrical aperture. In an experiment of this sort, the face held on the anvil remains open, while the hammered face tends to close. Thus, the head of the present object appears to have been hammered on one side only, viz., the side opposite to that represented in fig. 76. In all probability, the aperture was originally provided in casting the metal.

Object No. 12 (cf. Table I).

This object, illustrated in fig. 21, is a thin circular disc slightly dished from rim to center and bearing a slotted handle. Many objects of this sort have been found in Peru (the present collection embraces several) and they are generally supposed to have been used as mirrors. Baessler (l. c. 28) describes a similar object containing about 9 per cent tin. The present piece contains about 5.34 per cent tin and is distinctly inferior in whiteness to alloys containing 9 or 10 per cent tin. It is worthy of note that bronzes of this character, while capable of high polish, would require frequent polishing to preserve a highly reflecting surface as they tarnish readily. They are in no sense comparable to the copper-tin alloys known as speculum metal which contain in the neighborhood of 30 per cent tin and retain their lustre for a long time.

The order of curvature possessed by this disc may be sensed by referring to the diagram, fig. 78, which was prepared by running the pencil around the edges of a centrally located transverse section of the object placed face down on the paper. This serves as a diagram of position and two representative photo-micrographs are shown on the same plate. Fig. 79 represents the structure of the handle. This is an unworked casting structure, nearly homogenized by heat treatment, as shown by the faint, but readily distinguishable cores (shadowy markings all over the surface). Passing from the handle into the disc, the large irregularly bounded casting grains give place to a much finer recrystallized structure of the usual characteristics. This is quite uniform all over the section of the disc and is fairly represented by fig. 80, which, at the stated magnification (72×), practically spans the section from one side to the other at the point indicated. The grain count of 22 indicates a moderate annealing temperature; neighborhood of 750°. As in the case of most of these specimens, it is not possible to decide whether hot-working did or did not occur during some stage of the shaping process. The section examined bears evidence of undisturbed annealing after the hot- or cold-working had been effected and subsequent alteration in some places by cold-working, notably in the vicinity of the handle. Thus, whatever may have preceded, the final changes were produced by cold-working and the last severe work was probably done in the region of the handle.

Object No. 13 (cf. Table I).

This piece is chiefly of interest as an example of a partially completed object. By comparing fig. 22, illustrating the present object, with fig. 27, illustrating a form of tweezers commonly used for removing hair (cf. Joyce (6), p. 130), it is readily seen that the finished tweezers, except for the perforation, will result when the present shape is bent around into proper form. A section was prepared by sawing the piece along its middle line from end to end. A diagram of this section is given in fig. 81, and a photo-micrograph of the spot indicated is shown in fig. 82.

The grain count varies along the section from 13 to 25. This indicates that some parts were worked considerably more than others before the last annealing treatment, which, in view of the residual inhomogeneity (shadowy cores and distinct traces of the original tin-rich network), was of moderate intensity (e. g., brief period, neighborhood of 750°).

Object No. 14 (cf. Table I).

There are a large number of thin, flat knives in the collection of the form illustrated in fig. 20. Eight of these, in addition to the copper knife of similar form which has already been described, were analyzed (cf. Table I) and one was examined in the blade, shank and handle. As would be expected, a structure indicative of severe working with associated annealing was observed. The general conclusions drawn from the examination of the present object should apply fairly well in all cases.

Two structures at the upper end of the object have been chosen for reproduction. One of these, fig. 85, as may be seen from the adjacent diagram of position, fig. 83, represents the shank just before it bends around into the hook-shaped handle. Here, as well as all along the shank and handle, the sulphide constituent is threaded out to an extent indicative of at least 100 per cent elongation in the working of these parts. This condition was very closely duplicated by cold-rolling a piece of metal taken from Object No. 8, which contains a large quantity of normally equiaxed sulphide, so as to obtain an extension of 137½ per cent (from 16 mm. to 38 mm.). After extension to 35 mm. the piece was annealed by bringing it momentarily to red heat. The final condition is shown in fig. 87. This surface was prepared so as to show the continuity of the elongated sulphide particles as well as possible without regard to the detail of the matrix. In preparing fig. 85, this feature was not primarily considered and the smudgy appearance of the lines is due to imperfect preparation in this respect. The sulphide particles are, in reality, enormously extended without apparent fracture. In the blade of the knife, the particles of sulphide are small, numerous and often grouped, but not distinctly elongated in any one direction. It thus appears that the blade has been worked so as to extend the metal more or less uniformly in several directions. Photo-micrograph, fig. 84, represents the structure passing from the inner edge at the point of the bend towards the center. Very fine recrystallized grain is observed at the edge where the original grains were most severely overstrained in bending. Towards the center, where the minimum strain was felt, the original coarser grain is relatively little altered. These conditions would be produced by suitably annealing a bend formed in soft metal of the structural characteristics shown in fig. 85 and they indicate that the piece received annealing treatment after the handle was bent into shape. Scleroscopic tests on this object show hardness numbers of about 14 on the shank and 27 on the thin parts of the blade, which was set in plaster for these tests. Thus, there is considerable temper in the blade and some in the shank (soft, annealed alloys of this composition give hardness numbers below 10).

It may be said, in conclusion, that nothing can be learned from this examination relative to the original size and shape of the casting from which the knife was made. Several knives may have been made from one cast piece although there is no particular reason for believing this to be true. In any event, the casting structure is totally obliterated and the piece in its present condition cannot bear much resemblance to original stock used in its construction.

Object No. 15 (cf. Table I).

Only a small piece from the axe illustrated in fig. 23 was examined. This was cut from the extremity of one of the arms or branches forming the head, as shown in the diagram, fig. 88. The corresponding photo-micrograph is shown in fig. 89. Its comparatively fine grain (counting 28) indicates final annealing treatment hardly above dull red heat unless extremely brief, and the presence of faint cores indicates that the object has never been held at a temperature corresponding to bright redness for any considerable period of time. Deformational characteristics are present and the axe has been left in the hammer-hardened condition.

Object No. 16 (cf. Table I).

The object illustrated in fig. 24 appears to be a chisel which has been broken off about 2¾″ above the edge and twisted so that vertical planes passing through the edge and the opposite end, respectively, would intersect at an angle of about 12°. One of the vertical edges of the chisel was ground down flat, polished, etched, and examined along its entire length. A diagram of this surface is given in fig. 90. At 72×, the finer detail of the structure is imperfect owing to the small size of the recrystallized grains and the presence of prominent primary zonal structure. The general effect at this magnification is shown in fig. 91. All parts of the section look very nearly alike, but, under the higher powers, it is seen that the deformational characteristics are more pronounced in the vicinity of the edge; the cores, or zones, themselves show elongation near the edge and lines of deformation are abundant, both in the fragments of the primary grains and in the recrystallized grains. The structure of this portion is shown in fig. 92 at a magnification of 220×. Owing to the selective etching in copper-rich zones, the finer detail cannot be brought out with uniform clearness all over the surface; if the etching is carried far enough to bring out the detail in the light zones, it will be obscured in the dark zones (fig. 91); if it is only carried far enough to bring out the detail in the dark zones, there will be very little detail in the light zones, as in the present instance, fig. 92.

Scleroscopic tests confirm the micrographic conclusions, in that they show a maximum hardness number of 27 near the edge (⅛″ from the extreme edge) and a lower number, 15-16, in the body of the chisel. The grain count of 55, which was originally obtained at 220× and recalculated for the standard magnification, 72×, is only approximate but indicates, in connection with marked residual inhomogeneity, that the chisel has received only very light annealing treatment. From the character of the zones, in particular their equiaxed appearance, except near the very edge, it is clear that the present form of the object is not widely different from that of the casting used in making it.

Object No. 17 (cf. Table I).

This object is described in Table I as an irregular mass. The surface illustrated in fig. 25 is covered with large and small warty excrescences, while the opposite side is smooth and partially rounded at the edges. It is not improbable that the object is, in reality, a button which was left in the pot, or crucible, after pouring a heat of metal. In conformity with this assumption, the grain, as shown in fig. 94, at 12× and in fig. 95, at 72×, is coarse enough to indicate comparatively slow cooling. The tin-rich zones appear dark in both photomicrographs owing to their rounded character after etching and the corresponding inequalities of focus. Some patches of the $\alpha + \delta$ complex may be seen when the specimen is examined with the higher powers. Experiments with small castings of approximately this composition have shown that the metal cannot be brought to red heat without absorption of the complex. It is highly improbable that the present object has ever been annealed.

A number of twinning bands were observed on the surface of the section examined, fig. 93, which was cut, at random, from one side of the object. Several of these bands are shown near the center of fig. 95. They may represent congenital twinning in the sense that the object was forcibly handled so as to overstrain it locally just after it had set, or at a temperature high enough to cause recrystallization. Thus, the red-hot button may have been pulled or dumped from the pot.

Object No. 18 (cf. Table I).

The long, heavy needle illustrated in fig. 26 was examined only along a short longitudinal section passing down through the eye. A diagram of this is shown in fig. 96. The structure, at the point indicated, is shown in fig. 97. This point represents the mechanical union between the looped end of the metal and one of lateral flaps which is hammered down to hold it in place. The nature of this construction is well enough evident from the illustrations previously cited without further explanation. As may be seen in fig. 97, abundant lines of deformation remain in evidence of the severe hammering effected at this vicinity, i. e., the metal has not since been annealed. Scleroscopic tests have shown hardness numbers of 21, 18, and 15, at the points *a*, *b*, and *c*, respectively, of fig. 96. The grain count of 22 indicates that the last annealing treatment was of the type most frequently observed in these objects, viz., probably a brief period at moderate red heat.

Object No. 19 (cf. Table I).

Tweezers of the form illustrated in fig. 27 are well represented in the present collection. A partially completed specimen has already been described (No. 13). One of the finished specimens was flattened into the form which it obviously possessed before bending and polished on one side in those spots which reached the abrasive without resorting to deep cutting. After the examination, it was readily bent back into shape without any sign of fracture. This indicates that the metal was comparatively soft when originally bent into final shape. After being worked flat into proper form, it was probably annealed, pierced by driving a pointed object through the thin central portion, and then bent around into shape. The set of the aperture indicates that it was punched rather than drilled. The metal shows a finer recrystallized structure and more prominent cores than were encountered in the case of the partially completed specimen. It, therefore, received less drastic annealing treatment. Its structural characteristics are intermediate between those shown in fig. 49 and fig. 91, more closely approximating the latter. Such an effect would be produced by annealing for a few minutes (5-10) at 700°, or by just allowing the object to reach a temperature some 50° higher.

Object No. 20 (cf. Table I).

This object, which weighs over two pounds, is the most massive piece of the entire collection. As may be seen in fig. 28, it represents the lower portion of what may be conveniently called a crowbar. Scleroscopic tests on smooth-filed portions of the surface show that the metal was finished hard, i. e., the hardness numbers vary between 18 and 25. The bar was used in a tensile test which gave an elongation of 6 per cent in 2 inches and an ultimate strength of 27,800 pounds per square inch. Worked bronze of this composition, when hardened so as to possess very little ductility, should show far greater strength than was obtained in this case. The present combination of ductility and strength indicates metal of very poor quality. A polished and etched section near the fracture revealed a multitude of large and small holes with blackened, or oxidized surfaces. These predominate near the center of the cross section. Nearer the surface the holes have been closed in working the metal but without removing the source of weakness, since no true welding has occurred. The metal appears to have oxidized as a result of some initial porosity and much annealing treatment.

Object No. 21 (cf. Table I).

The small piece of metal illustrated in fig. 29 is one of several small shapes, bars, rods, etc., which probably constituted material intended for subsequent shaping into objects of some particular significance. This piece has been worked and annealed to a condition of complete homogeneity. The absence of deformational characteristics and the observed hardness number of 9-10 show that it is now soft and well adapted to further mechanical treatment.

Sheffield Scientific School of Yale University,
New Haven, Conn., June 20, 1915.

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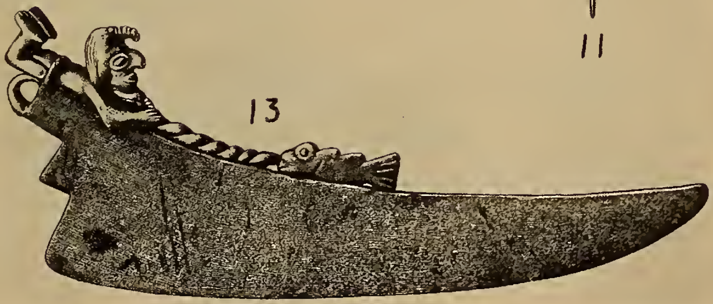

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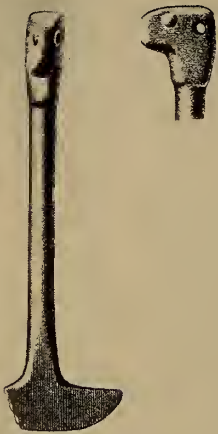

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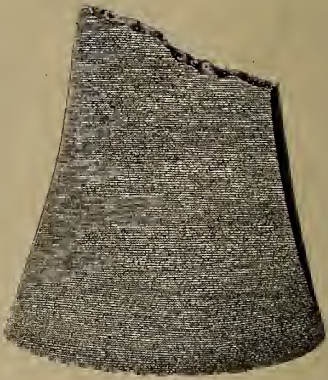

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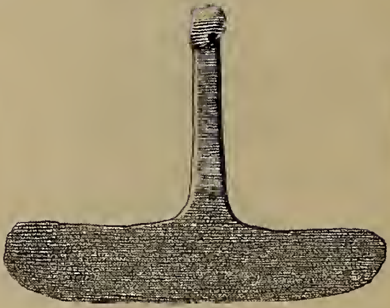

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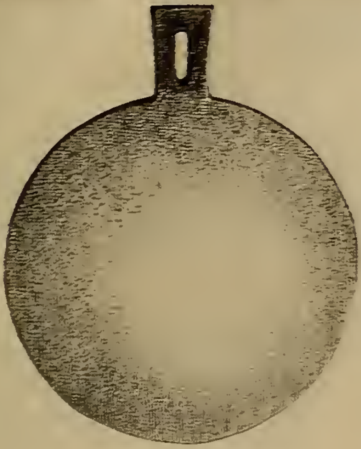

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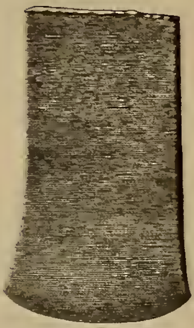

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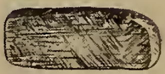

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Fig. 30.

Fig. 31.

Fig. 32.

Fig. 33.

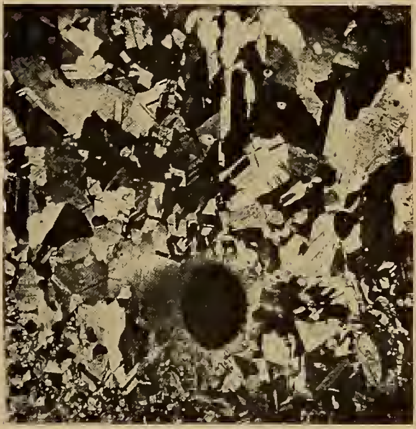


Fig. 34.

Fig. 35.

Magnification, 10×. Etched with acidified ferric chloride.—These photo-micrographs, together with those on the following pages, have been reduced one-eighth in the engravings.

Fig. 36.

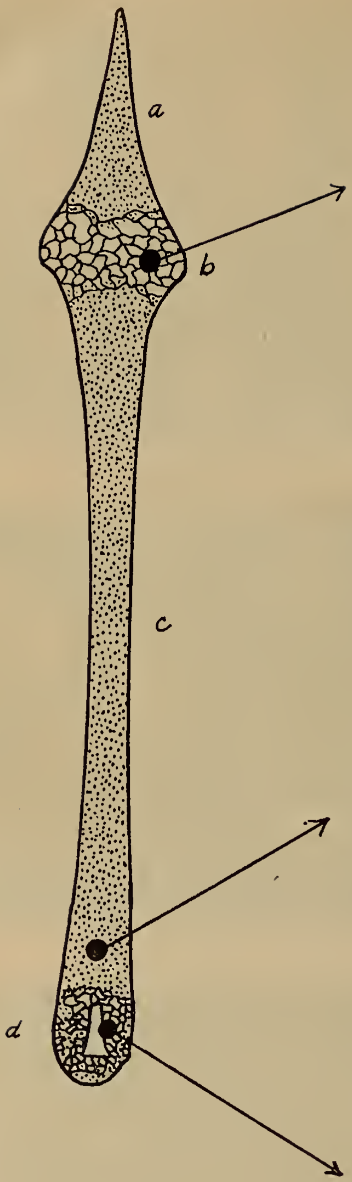


Fig. 37.

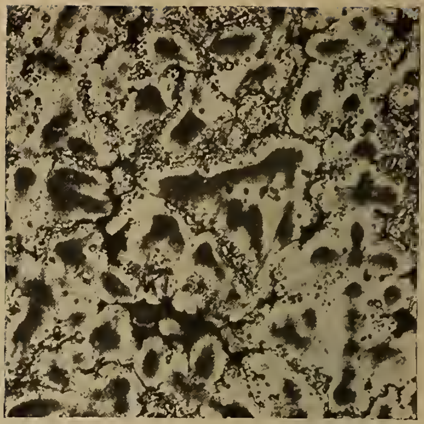


Fig. 38.

Fig. 39.

Magnification, 72× (see remarks on preceding page). Fig. 37, etched with ammonia and hydrogen peroxide, followed by acidified ferric chloride. Figs. 38, 39, etched with ammonia and hydrogen peroxide.

Fig. 41.

Fig. 42.

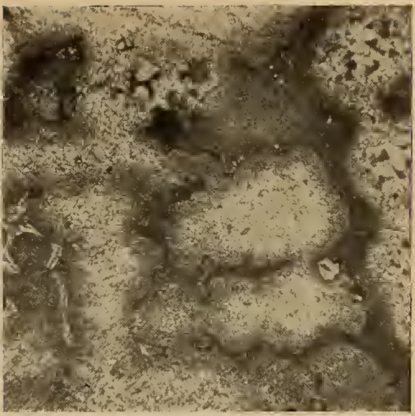


Fig. 40.

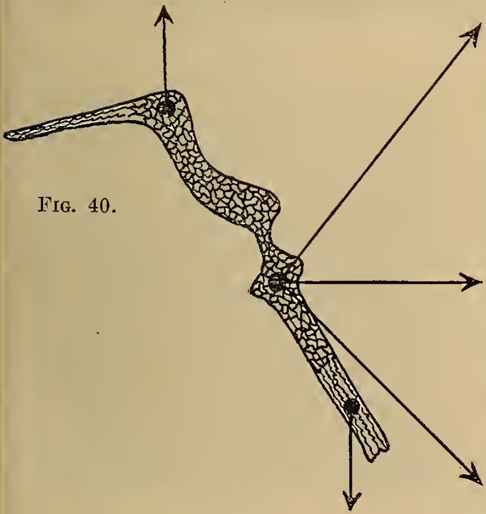


Fig. 43.

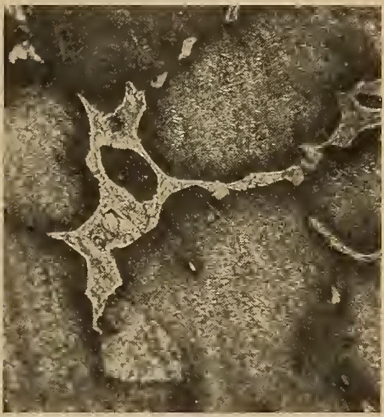


Fig. 44.

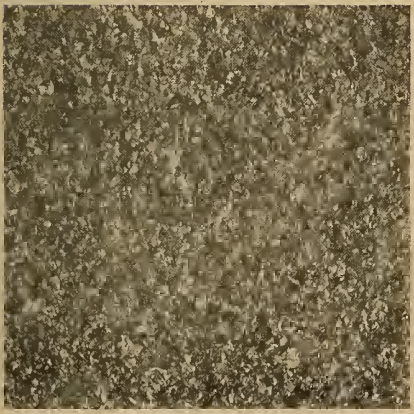
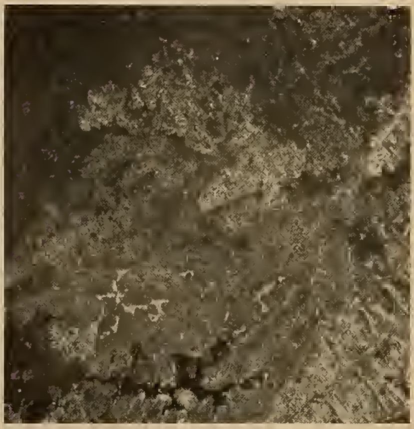


Fig. 45.



Figs. 41, 44, and 45, magnification, 72 ×. Figs. 42 and 43, magnification, 300 ×. Fig. 41, etched with ammonia and hydrogen peroxide, followed by acidified ferric chloride. Figs. 42, 43, 44, and 45, etched with acidified ferric chloride.

Fig. 47.

Fig. 46.

Fig. 48.

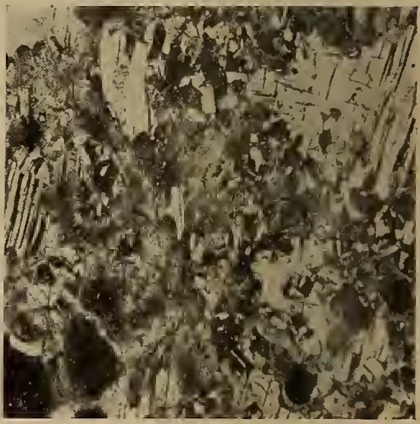


Fig. 49.

Fig. 47, magnification, 12 × . Fig. 48, magnification, 220 × . Fig. 49, magnification, 72 × . Figs. 47 and 48, etched with ammonia and hydrogen peroxide, followed by acidified ferric chloride. Fig. 49, etched with ammonia and hydrogen peroxide.

Fig. 50.

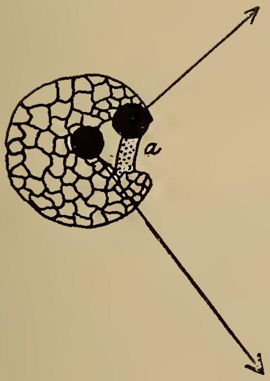
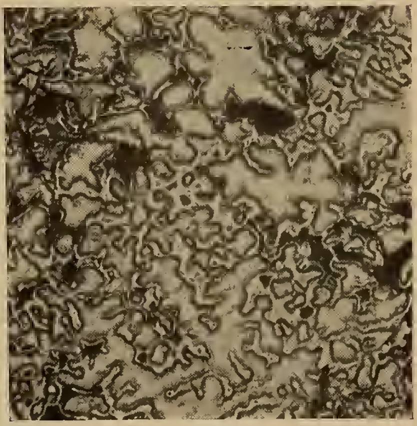


Fig. 51.

Fig. 52.

Fig. 53.

Fig. 54.



Figs. 51 and 52, magnification 18×. Fig. 54, magnification 72×. Figs. 51 and 52, etched with acidified ferric chloride. Fig. 54, etched with ammonia and hydrogen peroxide, followed by acidified ferric chloride.

Fig. 55.

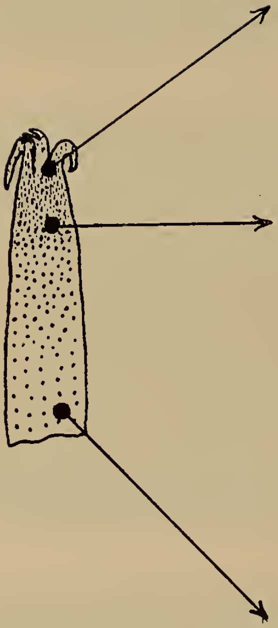


Fig. 56.

Fig. 57.

Fig. 58.

Magnification, 72×. Figs. 56 and 57, etched with ammonia and hydrogen peroxide. Fig. 58, etched with ammonia and hydrogen peroxide, followed by acidified ferric chloride.

FIG. 59.

FIG. 60.

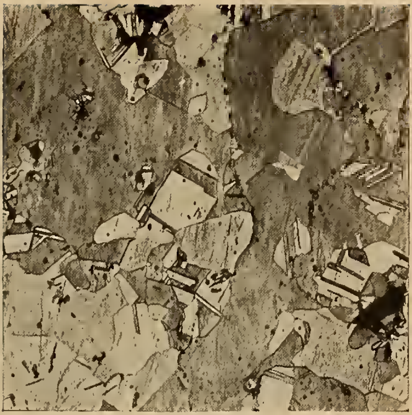


FIG. 61.

FIG. 62.

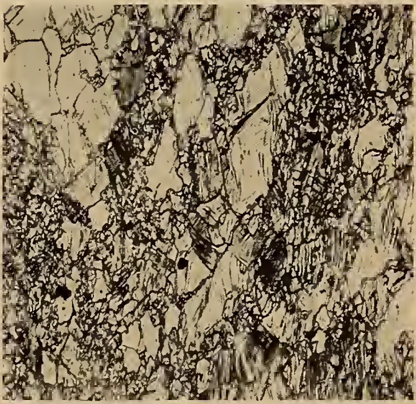
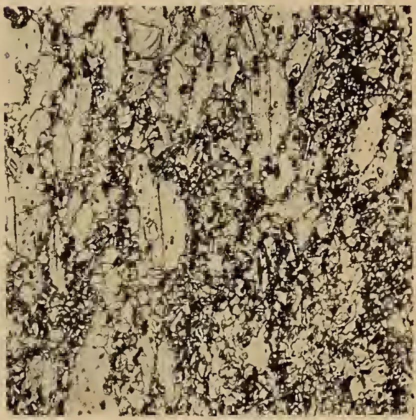


FIG. 63.

FIG. 64.



Magnification, 72 ×. Fig. 60, etched with ammonia and hydrogen peroxide, followed by acidified ferric chloride. Figs. 62 and 64, etched with ammonia and hydrogen peroxide.

Fig. 66.

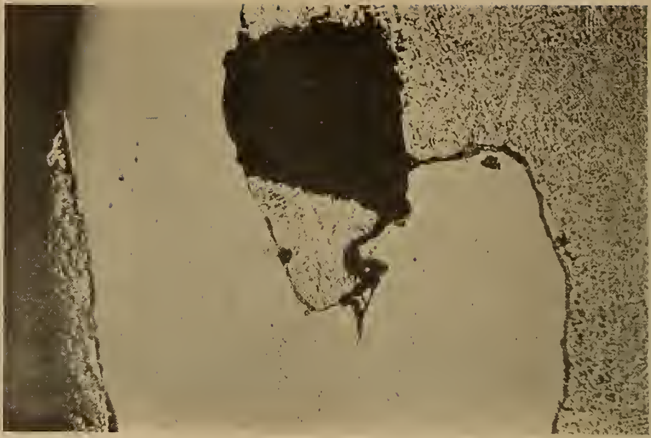


Fig. 65.

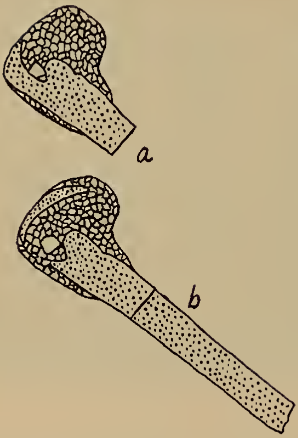


Fig. 67.

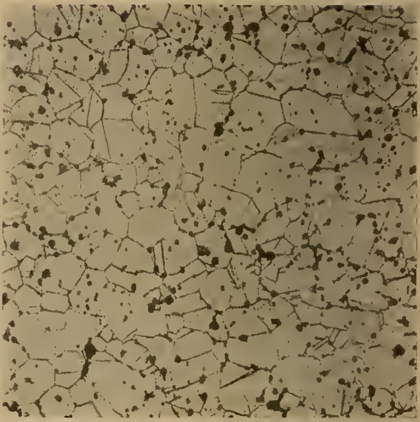


Fig. 68.

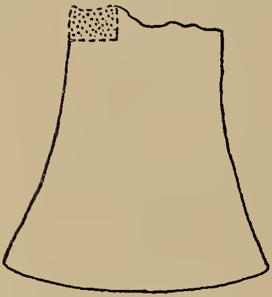


Fig. 69.

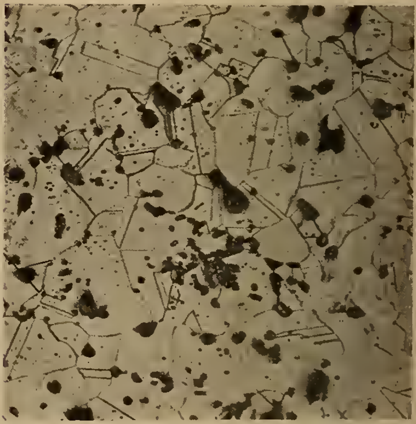


Fig. 66, magnification, 12 ×. Figs. 67 and 69, magnification, 72 ×. Fig. 66, unetched. Figs. 67 and 69, etched with ammonia and hydrogen peroxide.

Fig. 71.

Fig. 70.

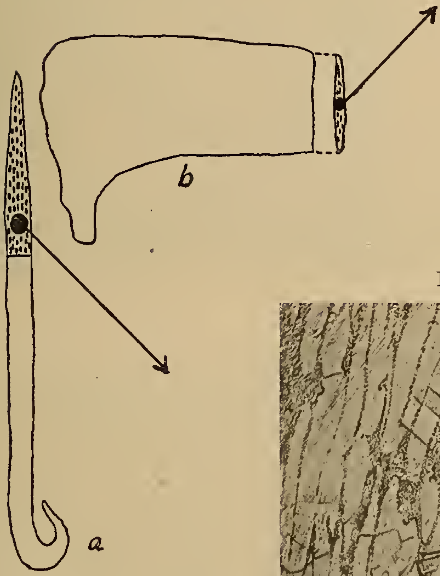
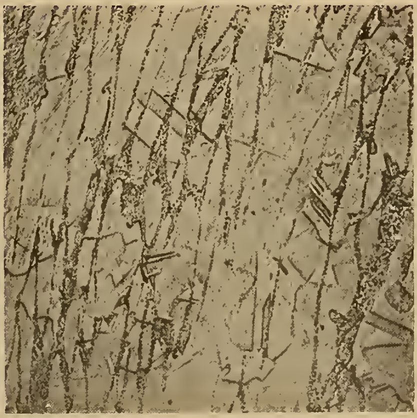


Fig. 72.



Magnification, 72 ×. Etched with ammonia and hydrogen peroxide.

FIG. 74.

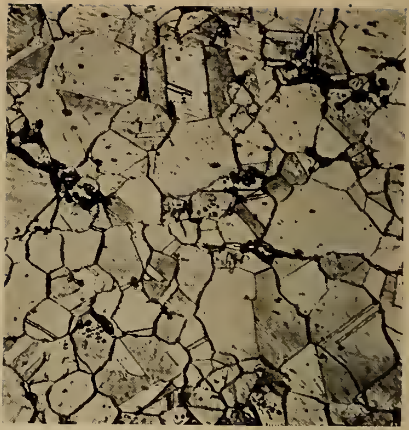


FIG. 73.

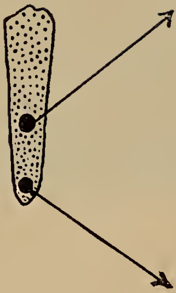


FIG. 75.

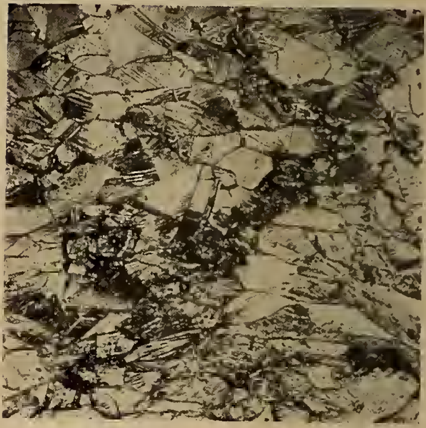


FIG. 76.

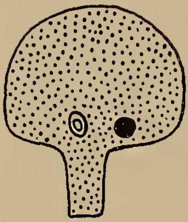
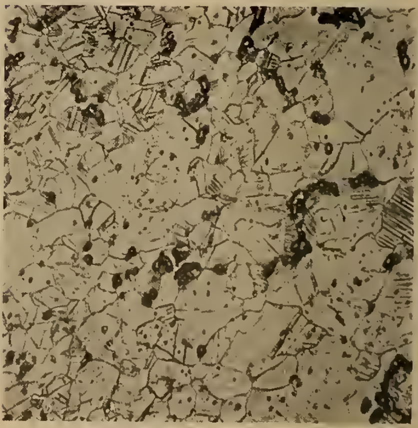


FIG. 77.



Magnification, 72 ×. Etched with ammonia and hydrogen peroxide.

Fig. 78.

Fig. 79.

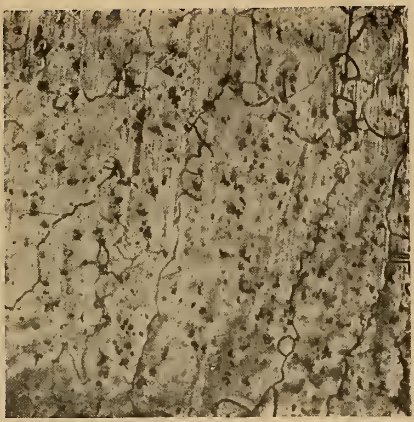


Fig. 80.

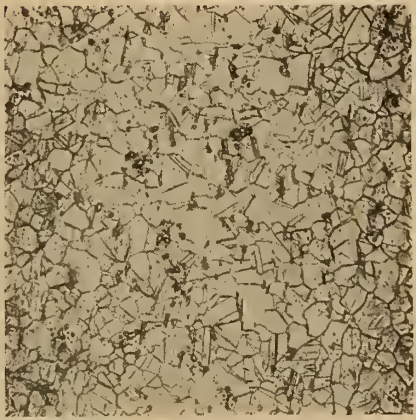


Fig. 81.

Fig. 82.

Magnification, 72 ×. Etched with ammonia and hydrogen peroxide.

Fig. 84.

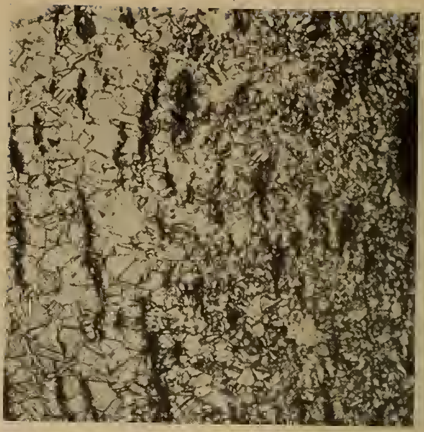


Fig. 83.

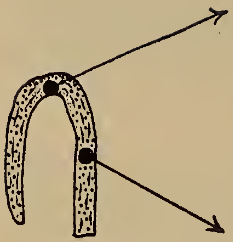


Fig. 85.

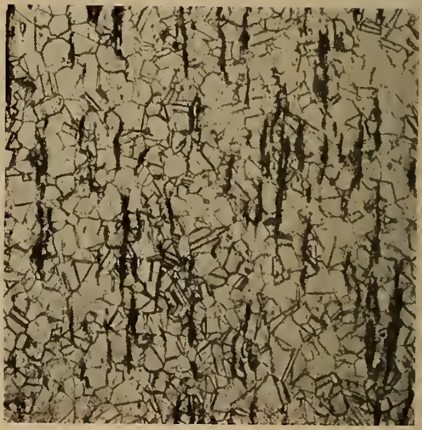
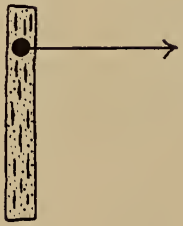


Fig. 87.

Fig. 86.



Magnification, 72 ×. Etched with ammonia and hydrogen peroxide.

Fig. 88.

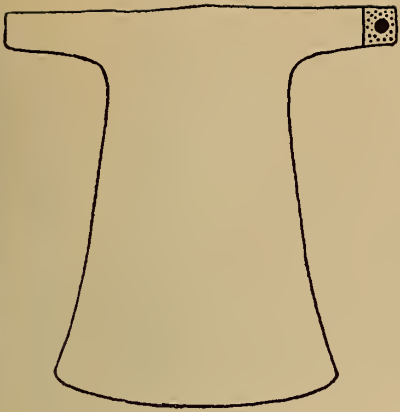


Fig. 89.

Fig. 91.

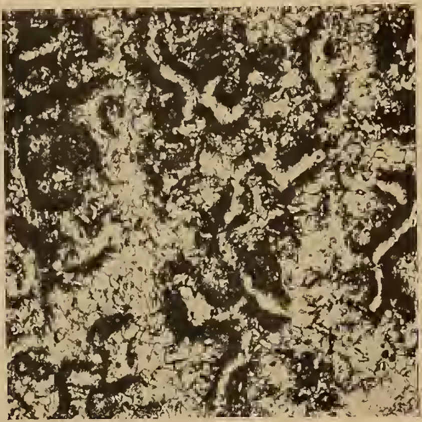


Fig. 90.

Fig. 92.

Figs. 89 and 91, magnification, 72 ×. Fig. 92, magnification, 220 ×. Etched with ammonia and hydrogen peroxide.

Fig. 94.

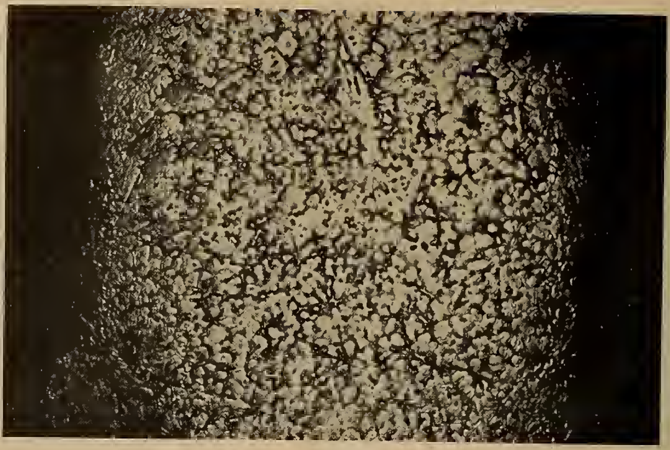


Fig. 93.

Fig. 95.

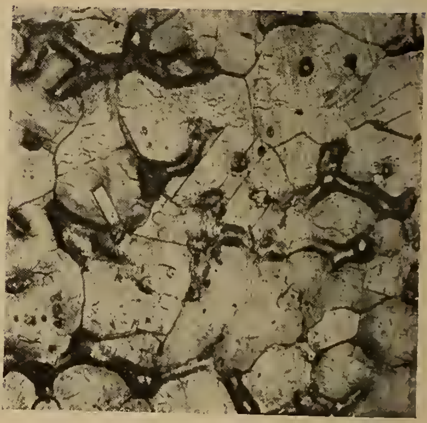


Fig. 96.

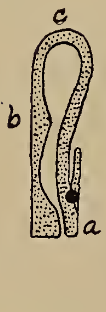


Fig. 97.

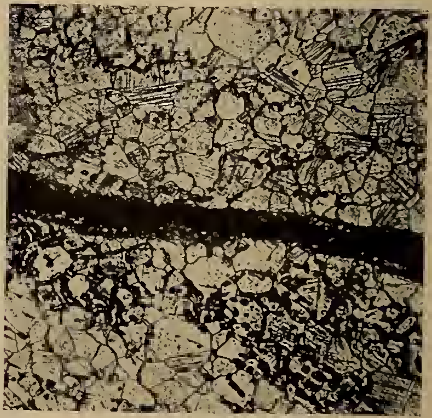


Fig. 94, magnification, 12×. Figs. 95 and 97, magnification, 72×. Etched with ammonia and hydrogen peroxide.

Art. XLII.—*A New Cephalopod from the Silurian of Pennsylvania*; by Ruth Raeder Mook.

Introduction.

During the summer of 1913 while working on the Bloomsburg Red Shale and the overlying limestones, in a limestone quarry about 7 miles southwest of Bloomsburg, Pennsylvania, the writer's attention was called to a rare cephalopod collected and owned by Mr. Guy A. Mowry of Grovania. The specimen was first discovered by quarrymen while excavating rock to be sent to the lime kilns. Mr. Mowry, who has carefully collected fossils for some years, was called in to make a careful note of the exact position and horizon of the specimen. The fossil was found in a bed of limestone, generally known in eastern Pennsylvania as the Bossardville, of Upper Silurian age.

So far as can at present be determined, a similar form has not yet been described for the United States, and because of its apparent rarity it has seemed worth while to call attention to it. Mr. Mowry has therefore kindly loaned the specimen for the purpose of description.

The name *Trochoceras grovaniense* is here proposed for this new species.

The genus Trochoceras.

The genus *Trochoceras* was proposed without any concert of action by Barrande in 1848 and Hall in 1852 for fossil species generically similar but not generically identical. At a meeting of the "Freunde der Naturwissenschaften in Wien," on September 10th, 1847, Dr. Franz v. Hauer called the attention of the members to some new cephalopods from the Silurian of Bohemia, which had been sent in by Barrande. The proceedings of this meeting were published in 1848.* The report included Barrande's original description of the genus *Trochoceras*, which reads as follows:

" *Trochoceras* (Barrande). The shell is characterized by the peculiar nature of its enrollment. The revolutions are laid upon one another in a spiral manner, so that the shell itself is not symmetrical. *Trochoceras* parallels therefore the genus *Turrilites* in the family of the *Ammonitidae*. All the species which Barrande discovered belong to the lower division of the

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*Berichte über die Mittheilungen von Freunden der Naturwissenschaften in Wien; gesammelt und herausgegeben von Wilhelm Haidinger, iii, Nr. 1–6, p. 264, July–December, 1847. Vienna, 1848.

Upper Silurian System.* No genotype was named. In a later volume of the same publication a list of species was given. In this list *Trochoceras davidsoni* was mentioned first and this is therefore Barrande's genotype.†

Fig. 1.

Fig. 1. Pencil drawing of type specimen of *Trochoceras grovaniense*, sp. nov. 7/16 nat. size.

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* Loc. cit., p. 266: "*Trochoceras* (Barrande). Durch die Art der Einrollung der Schale characterisirt. Die Umgänge sind nämlich in einer Schraubenlinie aneinandergelegt, so dass die Schale selbst nicht symmetrisch ist. *Trochoceras* entspricht demnach dem Geschlechte *Turrilites* aus der Familie der *Ammonitidae*. Alle Arten, die Barrande auffand, gehören der unteren Abteilung des oberen silurischen Systems an."

† Haidinger's Berichte, IV, p. 208, 1848.

The name proposed by Hall was printed in the second volume of the Paleontology of New York in 1850, although the volume was not issued until 1852.* Hall's genotype was *Trochoceras gebhardi.* His original description of the genus follows:

"Turbinate or trochiform; spire elevated, more or less ventricose, umbilicated; aperture rounded or round oval; volutions above the outer one septate; siphuncle submarginal or dorsal.

"In the specimen from which the generic description is principally made, the septa are strongly arched from the inner basal angle of the volution to the outer one, advancing on the outer angle towards the aperture." In the above description owing to a confusion of terms the siphuncle is recorded as submarginal or dorsal, whereas in present day usage it would be recorded as submarginal or ventral.

In 1894 Hyatt pointed out that Hall's species are quite distinct from Barrande's, and that they do not belong to any genus yet described from Bohemia. *Trochoceras* Barrande is not generically identical with *Trochoceras* Hall. Hyatt suggested that the name *Trochoceras* Barrande be retained and for Hall's forms *Trochoceras gebhardi* and *turbinatum* he proposed the new name *Mitroceras* with *Mitroceras* (*Troch.*) *gebhardi* as the genotype.† *Mitroceras* Hyatt differs from *Trochoceras* Barrande in the high turbinate spire, and in the deep and sharply angulate umbilicus.

Reasons for assigning the new species under discussion to the genus Trochoceras.

The formation in which the specimen under discussion was found has undergone little diastrophic movement. The beds dip at an angle of about 40 degrees to the south, but outside of uplifting and tilting there is no evidence of any great disturbance such as twisting, mashing, etc. In the overlying formation, the so-called Bastard limestone, fossils are abundantly preserved and show no evidences of distortion. The specimen under discussion is considerably warped, apparently indicating that it was a low spired trochoceracone rather than a flat nautilicone; its warped condition then can be reasonably explained by the normal crushing of a cone-shaped shell.

Trochoceras grovaniense sp. nov.

Shell large, probably trochiform; spire very slightly elevated; maximum diameter 158^{mm}; diameter of outer whorl

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* Palaeontology of New York by James Hall; vol. ii, p. 335. Albany, 1852.

† Phylogeny of an Acquired Characteristic. Alpheus Hyatt. Proc. Amer. Phil. Soc., vol. xxxii, No. 143, p. 502, 1894.

about 25^{mm} (varying according to state of compression); number of whorls 4, the outer one incomplete; increase in diameter of whorls *very* gradual; diameter of inner whorl about 10^{mm}; septa simple, very slightly curved, about 4^{mm} apart on outer whorl and 3^{mm} apart on inner side of inner whorl; annulations on outer whorl about $2{\cdot}5^{mm}$ apart; siphuncle ventral.

Owing to the crushed condition and poor preservation of the shell the extent of the elevation of the spire is unknown. From the irregular warped surface of the specimen it seems reasonable to suppose that the spire was very broad and low. The exact nature of the umbilicus is indeterminate; presumably it was broad, shallow, and not angular. The precise character of the siphuncle is also unknown. There is only one place on the shell where the siphuncle appears; here it is only very poorly preserved. Its ventral position, however, can be determined.

Trochoceras grovaniense seems most nearly related to *T. priscum* Barrande, Etage$_2$ of Bohemia. It differs from the latter in its greater size, more gradual increase in the size of the whorls, an d n having the septa straighter and slightly farther apart.

Paleontological Laboratory, Columbia University.

ART. XLIII.—*Activity of Mauna Loa, Hawaii, December–January, 1914–15*; by T. A. JAGGAR, JR.

THE activity of Mauna Loa, inaugurated November 25, 1914,[*] continued through December and part of January at the summit crater and then ceased, this movement constituting the first phase of a new eruptive period, quite in accord with the habit of this volcano. No lava flow from the flank of the volcano has occurred up to the time of writing (July 22, 1915), and none need be expected for some years. The notes which follow are taken from the records of the Hawaiian Volcano Observatory.

The following corrections should be noted of statements made by the writer in his previous notes.[*] The interval of repose preceding this outbreak was the maximum recorded since 1868, for it appears that within the eight years from 1888 to 1895, a summit outbreak occurred, namely November 30–December 2, 1892, previously overlooked when that interval was cited as the maximum. This outbreak of 1892 is considered a first preliminary of the eruptive period which culminated in the lava flow of 1899, the second preliminary occurring in 1896. If we treat a complete eruption as consisting of one or more preliminary summit fountainings leading to a concluding lava flow, then the intervals of repose have been as follows:

1868, April, to 1870, January	20 months
1877, February, to 1880, May	38 "
1881, November, to 1887, January	62 "
1887, February, to 1892, December	70 "
1899, August, to 1903, September	50 "
1907, February, to 1914, November	93 "

There is clearly a suggestion here of gradually increasing intervals.

A second correction concerns the hour of outbreak November 25, 1914. It was at first supposed to be about 3.45 p. m. according to observers at Pahala (fig. 1), but later advice made it clear that cattle herders of Kapapala Ranch saw the fumes rising from the summit crater about 12.25 p. m. just when the seismographs at the Observatory were registering prolonged motion. Two other corrections are to the effect that part of the north lunate platform in Mokuaweoweo crater still persists, although not shown in Mr. Palmer's map,[†] and that while no

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[*] The Outbreak of Mauna Loa, Hawaii, 1914, by T. A. Jaggar, Jr., this Journal, vol. xxxix, pp. 167–172, Feb. 1915.

[†] This Journal, Feb. 1915, page 171.

FIG. 1.

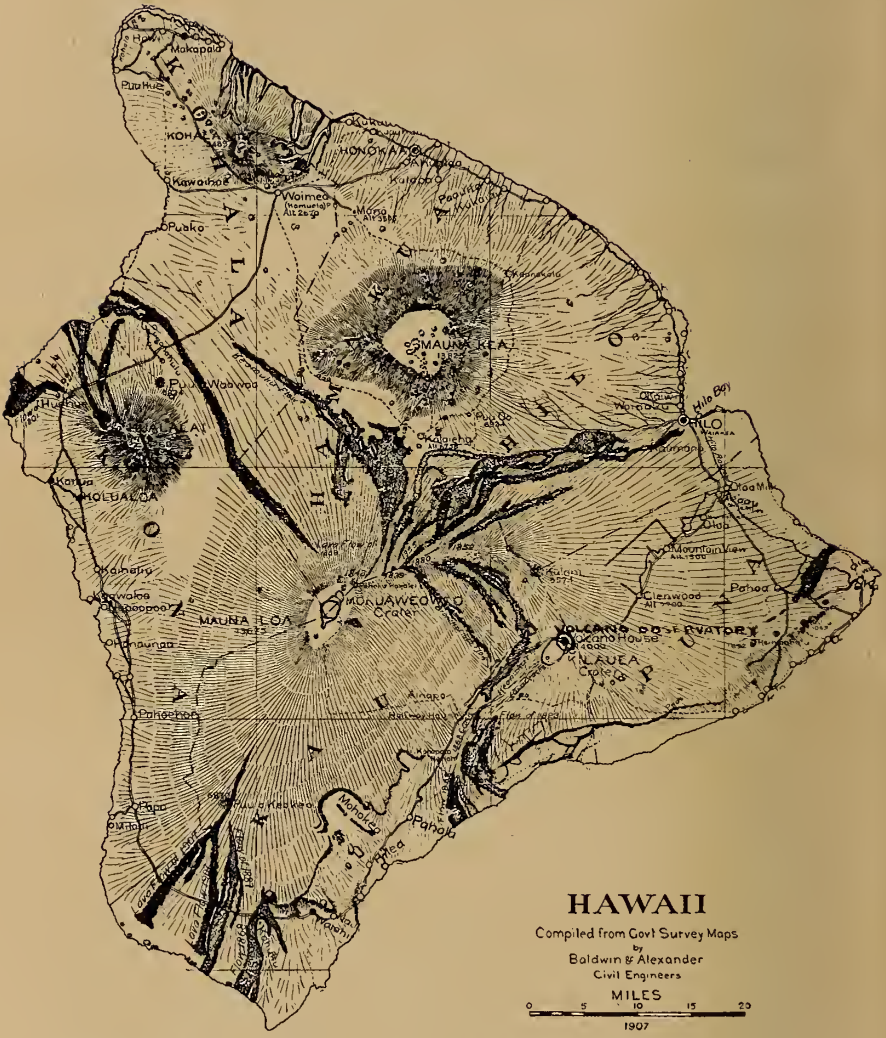

FIG. 1. Map of Hawaii (from Baldwin's Geography of the Hawaiian Islands).

instantaneous sympathy with the eruption of Mauna Loa was shown by Kilauea, yet there was a very pronounced rise of the Kilauea lava column which immediately followed the date of the Mauna Loa outbreak November 25. (Fig. 2.)

The seismic prelude to the eruption has been described by H. O. Wood.* The number of local shocks per month was as follows:

April	17 shocks.	August–September, incompletely recorded.	
May	11 "	October	14 shocks.
June	13 "	November	74 "
July	34 "	December	13 "

FIG. 2.

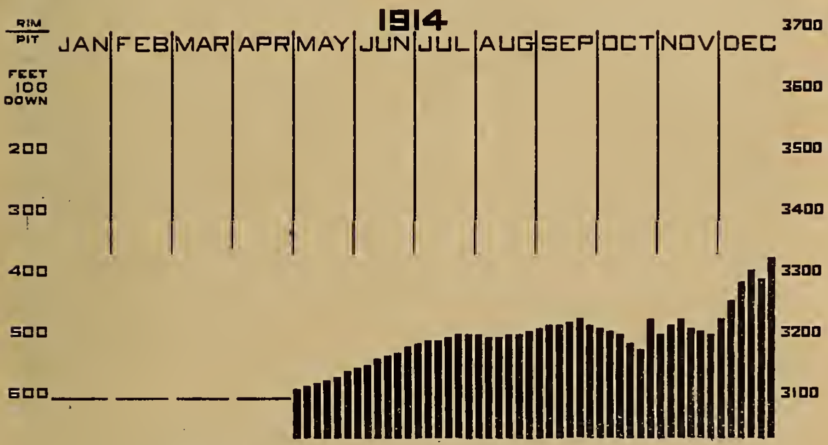

FIG. 2. Diagram showing rise of lava column of Kilauea volcano, in Halemaumau Pit during year 1914, and rapid acceleration after November 25, the date of Mauna Loa outbreak. By T. A. Jaggar.

During the year preceding October 1914 there were at least two sharp shocks on Hawaii, one of them in the Mauna Loa axis; and in July and September there were seismic spasms of numerous earthquakes lasting two or three days. The computed distance of origin of many of the local earthquakes of the year, notably from September to December, corresponded to the distance from the Observatory to the Mauna Loa rift line, namely eighteen to thirty miles. Immediately after the outbreak, from November to December 8 inclusive, eleven days, no earthquakes were registered at the Observatory, show-

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* The Seismic Prelude to the 1914 Eruption of Mauna Loa, by Harry O. Wood, Bull. Seis. Soc. Amer., vol. v, pp. 39–50, March 1915.

ing a sudden cessation in seismic activity. In the first half of 1915 the seismicity has been normal.

All the evidence accumulated concerning this summit outbreak of Mauna Loa shows that the main eruption expended itself during the first twelve hours in a line of tremendous lava fountains rising through a rift in the crater floor and probably spouting to heights over five hundred feet in some instances. No one saw the fountains from the rim of the crater during the first two days, and it is probably no exaggeration to assert that no one has ever seen an outbreak of Mauna Loa from a viewpoint close at hand. These first twelve hours presented a spectacle quite different from what was seen by Palmer and Forrest on the third day, for those observers reported spatter heaps of large size beside dwindled fountains which had built them, and night photographs taken by the writer November 26* and November 27 under like conditions of distance, light

Fig. 3.

Fig. 3. Mauna Loa and Kilauea from east rim of Kilauea crater Nov. 26. 1914, 12.30 a. m. The width of the fume column in Mauna Loa calculated from measurement of photograph was 7300 feet, or approximately 1·4 miles; the distance 116,250 feet or 22 miles. South is on the left. T. A. Jaggar, phot.

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* This Journal, Feb. 1915, page 165.

and exposure show striking dwindling in the luminosity of the fume column. On November 26 the brilliantly-lighted jets of vapor formed a wide band corresponding to more than one mile of summit rift (fig. 3), while on November 27 the band had narrowed, was brightly luminous only in one southern streak with a faint secondary streak north of it. (Fig. 4.) The sudden outbreak and intense activity of the first few hours correspond to the explosive phase of the first few hours of eruption in other volcanoes such as Vesuvius, and undoubtedly marked a sudden release of gas pressure in a foaming liquid of relatively low viscosity. The seismic prelude implies that for some months the lava was pushing its way upward, probably by a combination of blowpiping, stoping and wedging.

FIG. 4.

FIG. 4. Camp and glow over Mokuaweoweo, Puu Lehua, Kona, Nov. 27, 1914, 10 P. M. Photographed by moonlight; 25 min. exposure; Wratten panchromatic plate, Tessar lens; conditions similar to fig. 3 as to clearness and distance but on opposite side of mountain. South is on the right. T. A. Jaggar, phot.

On November 26, from the observatory, a clear view of the profile of Mauna Loa at about 9 a. m. showed a cluster of fume columns, merging into a fluted curtain of thin bluish-white fumes rising quietly to a position subtending an angle above the summit about two-thirds as great as that subtended by the summit above the level of Kilauea, hence attaining an altitude of 6000 to 7000 feet above the summit, where a scanty cumulus crown of condensed vapor hung. (Fig. 5.)

Presumably this was condensed water vapor from the atmosphere. All about it was a very thin, much diffused bluish haze of uncondensed fumes. By day the effect was disappointingly slight. Drifting clouds during forenoon and afternoon made seeing uncertain. Toward sundown, however, clear seeing was again afforded. Seen in sunset lighting, partly by reflected, partly by transmitted light, the thin fume curtain—now chiefly a north and a south column—displayed a succession of color tints of distinctly fluorescent character, as follows: (*a*) just before sunset, with the sun on the mountain profile well south of the summit, the fumes showed a dirty saffron tint, seen largely by reflected light; (*b*) at about ten minutes after sunset this had gradually turned to brown, in which a distinctly greenish cast was seen; it was still a muddy color, though seen largely by transmitted light; (*c*) about twenty minutes after sunset the tone had become a deep, translucent brown, still of somewhat muddy consistency.

Fig. 5.

Seeing in the evening was much interrupted by mist. Meteorological conditions at the summit were unquestionably less favorable for a spectacular display than on the evening of outbreak. Nevertheless it appeared certain that the active area had decreased. There were two well-marked columns of rising fumes, the southern larger and better illuminated. Usually these were separated by a blank space of clear sky, but at times illuminated drifting fumes intervened.

On November 27, by day only brief glimpses of the top of the fume column were obtained. At night the scene was essentially unchanged, though somewhat more spectacular than on the previous evening.

On November 28, forenoon views were like those of the preceding days. Heavy rain set in about noon and there was no further seeing.

On November 29, no view was obtained till late afternoon and evening. The summit was seen to be covered with snow down to about 12,000 feet. There was no significant change in the action from that seen on Friday evening, November 27.

On November 30, at about 10 a. m. the north fume column was seen to be very much lessened. At night in bright, hazy moonlight the display was brilliant and quite as spectacular as at any time except the first evening and night. Nevertheless the output of fumes was less than on the preceding evenings. The south column of fumes was much the larger, and better illuminated. The dark space intervening between it and the north column was occasionally filled with drifting fumes well lighted.

On December 1, an overcast day with very high clouds, the fumes showed faint brown tints against the cloud background in early forenoon. A stratum of very thin, cerulean blue fumes, with a faint but distinctly defined limiting plane at the bottom, rested upon the mountain above, about 10,000 feet. In the afternoon only the south fume column was any longer visible. This rose, straight and slender, from 9,000 to 10,000 feet above the summit, and there a ragged cumulus crown hung stationary in a streaked, wavy network of blue haze. In the evening the slender fume column was faintly illuminated and soon obscured by drifting clouds.

On December 2, no view was obtained until evening. Then, at first the single south fume column appeared dimly lighted, almost invisible in the bright light of the full moon, but soon fumes appeared to be rising more copiously and more rapidly and the column became very brilliantly lighted, as much so as at any time except on the night of outbreak.

Seen from the Observatory, on December 3 in the evening, Mauna Loa cleared under high clouds, showing a single smoke column more voluminous than on previous days and more spectacularly illuminated. December 4 and 5 there was rain, but a faint diffused illumination of the cloud cap was seen at night. December 6, at half-past nine p.m., Mauna Loa cleared off, showing a single slender column of fume with orange light of about the same color as Halemaumau, rising rapidly in puffs discernible even at this great distance (twenty-two miles) to a height of about 6000 feet, and there spreading into a diffuse mushroom or balloon of thin vapor, illumined ruddy. (Fig. 6.) The topmost detectable glow reached to at least 10,000 feet above the summit. The next morning, Monday, December 7, at 8 a. m., Mauna Loa was revealed with a wide snow cap, and from its middle rose a very slender column of white vapor, diffused above into a bluish haze. On the next morning, December 8, the mountain was brilliantly clear and showed not the faintest trace of a fume column, and there was no night glow seen, though the mountain was clear at 4 a. m., December 10. At 8.30 p. m., however, a faint glow showed and this continued on the 11th. Dec. 12 there were faint fumes in the morning and fumes with glow in the evening. Dec. 13 a compact cloud appeared over the crater in the morning, there were light puffs rising at 5 p. m. and the glow was distinct at night.

Fig. 6.

We succeeded on December 15 in reaching Mokuaweoweo from the east side and taking photographs and notes of the fountaining activity which continued there.

There had now been five parties which reached the summit area, and only one of these, the first, Messrs. Forrest and

Palmer, on November 27, succeeded in spending the night there. Owing to high winds and snow the December parties had to content themselves with daylight views. The parties named were Forrest and Palmer, November 27; Jaggar, November 28; Charles Ka, December 3; Baker and Bowdish, December 11; Volcano Observatory expedition, December 15.

Three of the expeditions attempted to camp at the summit and failed, owing to weather conditions. The expense in the case of the Observatory's trips has been enormously out of proportion to the small results achieved, owing wholly to the lack of any shelter in the summit area. The lessons learned in this respect, however, have been of great value. The Mauna Loa summit region cannot be a place of good scientific observation and survey until a shelter hut and stable have been erected there.

Dr. A. S. Baker and Mr. A. C. Bowdish ascended Mauna Loa from Kona December 10, and Mr. Bowdish described what he saw in the Honolulu Star Bulletin of December 15, 1914. He reached the western edge of Moknaweoweo on the morning of December 11, and "saw one cone still active, throwing lava up 150 feet or more, while nearby was a bowl that was boiling, splashing lava to the height of 50 feet or more. Just beyond these to the south was a narrow line of fire where a stream of lava had not fully cooled on the surface. There was smoke issuing at a dozen or more places in comparatively small volumes, but no fire was visible or other cones in sight. The whole floor was a vast black surface showing the chilled walls of lava streams apparently no longer active. The active cone is from 50 to 150 feet high, and the lava was thrown up three times the distance of the height of the cone above its crest. The lava lost its first color before it reached the highest point and became black." (Fig. 7.)

The Observatory expedition left Volcano House Monday, December 14, at 9 a. m., by motor car for the upper cattle pen of Kapapala ranch, below the Halfway House. At 10:30 the pack train was loaded and it reached the water tank and camp ground in the forest reservation, at an elevation of about 8000 feet, at 4 p. m. and camp was made for the night. There were eight men with riding animals and five pack animals. The party was H. O. Wood, D. Lycurgus, Mr. Withers, Mr. Hannon, Alex Lancaster, Joe de Mello and H. Kaukine, besides the writer.

December 15 start was made for the summit with the packs at 7.30 a. m., and before noon, in the snow-covered summit region, a gale of wind from the southwest sprang up. This was bitterly cold and the animals could barely make progress against it. The weather was cloudy but without snowfall or rain.

The snow of the summit plateau was deep and crusted over, so that it generally supported horses without their plunging through the crust, but one or two of the animals went through. There was perhaps the equivalent of a foot of snow on the level, drifted deep into the hollows, and revealing points of rocks.

As there was no diminution of wind on the summit plateau, which was reached at 12.30 p. m., I sent the pack animals back to the lower camp and all but the two packers proceeded to the crater. It was quite impracticable to make camp in such a gale, and in deep snow, with every prospect of a possible storm.

FIG. 7.

FIG. 7. Southwest edge of Mokuaweoweo crater, Feb. 1912. J. F. Rock, phot.

There are no ridges to offer protection, only a waste of pahoehoe and aa blanketed with snow and occasional concealed crevasses. This plateau extends about four miles from the edge of the crater on the east side, but the west or Kona side is the actual summit of Mauna Loa and slopes off rapidly westward. We reached the east margin of Mokuaweoweo at 1.15 p. m.

above the east end of the south lunate platform as mapped by Alexander in 1885. We looked across the south half of the main crater circle, which in general is much like the greater crater of Kilauea, and saw a large red fountain playing continuously in the southwest part of the crater. The fountain rose from the northwest side of an oval pool of crusted pumiceous lava, and back of the fountain was a huge half-cone of its own building. All of this was a mile away, as though one looked from the Volcano House of Kilauea at a fountain playing near the foot of Uwekahuna bluff, the great west cliff of Kilauea crater.

Fig. 8.

Fig. 8. Lava pool and fountains of Mokuaweoweo from east margin of crater, Dec. 15, 1914, 1.30 p. m. The main fountain shows white with a dark half-cone behind it and fume cloud above. T. A. Jaggar, phot.

The fountain played steadily to a height of about a hundred feet, and its horizontal diameter was about the same. Above this it sent up jets fifty feet higher, which parted into many fragments, cooling through shades of cherry-red to claret-color and black, and these black ejecta, instead of falling heavily, floated away and fell slowly like burnt paper, showing that the lava was of a very light, pumice-like quality. (Fig. 8.) The heights may have been greater than above stated.

The falling spatter from the fountain was to the west and north, and here on the edge of the pool was a black mound, probably crescent-shaped in plan, and steep or overhanging on the side of the fountain like the oven ramparts that build over grottoes around the borders of the Kilauea lake.

This spatter heap was at least seventy-five feet high and made part of the background of the great fountain. Lower ramparts engirdled the oval lake, which stood relatively high above a region of black pools and flows south of it and from it. The west side of the lake exhibited other lower fountains, one of them building a small mound, and mostly in the line of the big fountain and along the shore of the pool. Other fountains broke through the crust of the pool from place to place and time to time, seemingly indicating that the black crust was foamy or light and easily punctured. The fountains were indescribably different from the relatively heavy domes like Old Faithful in Halemauman. They were strikingly like the flamy protuberances in the pictures of the solar corona.

They appeared to me much redder in daylight and more like flames than a heavy liquid. The suggestion was rather as of an exceedingly light and gas-charged liquid, which cooled and changed color even more quickly than the fluid of Kilauea, and which boiled to much greater heights because of its aeriform consistency.

In the high wind which was blowing very little smoke showed. Above the fountains, however, a blue fume developed in volutes and rose. Between the large fountain and the fume above it, appeared a semi-transparent space with strong uprushing heat-movement lines, which gave me the impression of being a bluish flame which in darkness would have shown as such. To Mr. Arthur Hannon, an artist in the party, this appeared of violet color and a distinct flame. The only smoking area was in the vicinity of the heated pool and the flows below it to the south.

The rest of the crater appeared much as in 1912 and 1913, except that new detail of small mounds appeared along a fissure line northward from the large fountain and beyond the great mound or cone of 1903. Mr. Palmer's map will serve to illustrate the line of the rift, and no doubt there are new flows from this fissure over the middle region of the crater. The larger central mounds, however, shown on his map are not new, but are the old cones of 1903–1907, somewhat modified by the new eruption. (This Journal, Feb. 1915, 171.)

No changes were seen in the walls of Mokuaweoweo nor in the north or south pits, though we could not see into the latter. The southern lunate bench and parts of the crater floor were covered with snow, but not the central, southern and north-central parts of the main crater, implying, perhaps, that all of that region was warm. Remnants of the north lunate bench still persist but show change since last year. The north gateway to the crater formed a frame for a striking view of Mauna Kea, with its snow-covered upper cones. (Fig. 9.)

The party left the summit at 2 p. m. and reached the lower camp at 5. One of the animals was quite exhausted, owing to feet cut by the rough trail in aa lava, and was unable to hold out through the return trip next day. On December 16 we left the camp at 8.45 a. m. and reached the highroad soon after noon.

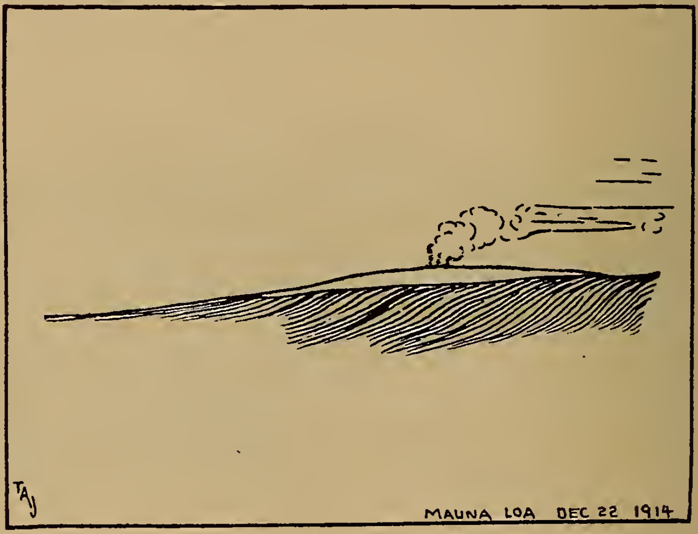
FIG. 9.

FIG. 9. Northeast wall of Mokuaweoweo, Dec. 15, 1914, showing floor devoid of snow and distant Mauna Kea. T. A. Jaggar, phot.

The summit glow and fume column on Mauna Loa during the fortnight ending December 24 were visible in clear weather over Mokuaweoweo without marked change. December 22 there was a deep mantle of snow on the mountain. (Fig. 10.) The fume column was very clearly visible at the end of December owing to exceptionally transparent air. It made a visible gauge of wind direction on the summit, often quite different from the wind below, and gradually developed the habit of puffing up in distinct volutes, as the supply became less.

December 26, the slender single fume column was glowing in the evening. December 27, from 7 to 9 a. m. (fig. 11), with light northeast wind at Volcano House, the fume column on Mauna Loa rose high, bent eastward and thinned out over Puna to a bluish iridescent fume cirrus, quite unlike any rain cloud in color and luster. It showed a slight transverse ripple-marking in the middle part of its course. There was possibly a slight increase in volume of fumes, which continued through the week, but owing to varying conditions of wind and of clear atmosphere, with frequently no seeing at all, it is impossible to judge slight changes accurately.

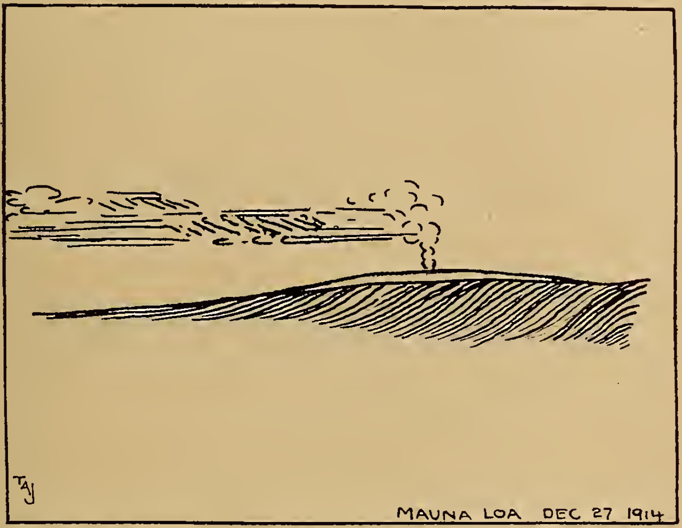
Fig. 10.



An increase of fumes was to be looked for, by analogy with the habit of Kilauea, if the fountains in Mokuaweoweo were still diminishing. The glow at night continued through the week. December 28, in the morning, small volutes of fume were rising; December 29, a straight funnel column in still air with traces of vortex motion in a spiral (fig. 12); December 30, the same, bending in a counter current eastward in upper atmosphere, while the wind was northeast below. (Fig. 13.) At 1 p. m. the high column was bending southward, the puffs showing brownish below and blue above. The morning of December 31, with northeast wind continuing below, the fume puffs of Mokuaweoweo were blowing away westward, implying that the wind below and above was now one and the same, and that the trade wind stratum had in the last few days thickened to above 14,000 feet.

The first week of the new year 1915 found the Hawaiian volcanoes Mauna Loa and Kilauea both in a state of activity, the former with one or more fountains of brilliant lava foam continuously playing in the southwestern part of the summit crater Mokuaweoweo, the latter with a lively lake and three smaller lava ponds 368 feet below the rim of the crater pit Halemaumau.

Fig. 11.



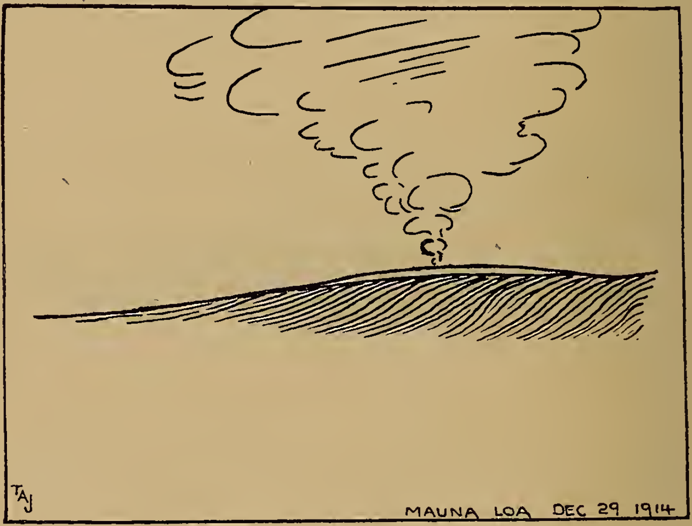
The fume and glow over Mokuaweoweo continued constant. December 31, the fume was blowing to the northwest. January 1, the fume blew westward, making the column a low dome as seen from the Observatory, with glow at night.

January 2, there was a northeast drizzle with tremendous squalls of wind at the Observatory; the Mauna Loa fume appeared to be blowing southeast. In the afternoon there was a crown of rain-cloud above the snow-line on Mauna Loa, with the blue fume funnel rising vertically from its midst and bending east above. The sunset was brown-yellow, with the fume-streak crossing it. The night was clear, showing not only the illumined fume-column but a marked radiant glow spreading upward in the atmosphere above the summit fountains.

January 3, very small puffs of fume showed, apparently blowing west, and this continued January 4, the nights showing the radiant glow and occasionally the low illumined fume. January 5 was similar, but the fume dome rose higher and at night there was a high luminous zone and rare glimpses of the fume top. There was fresh snow on the mountain. January 6, the fume was blowing northwestward.

By the middle of January every expectation based on the hypothesis that Hawaiian volcanoes respond to the solstice and subside thereafter, was fulfilled, for the lava of Halemaumau was rapidly sinking and on January 11 the fume column and glow of the Mokuaweoweo fountain ceased.

Fig. 12.

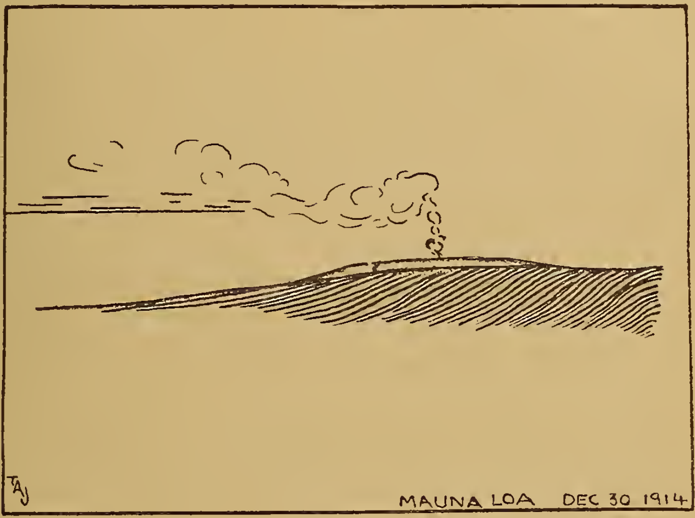


The time of the solstice, or maximum declination of the sun south, was from December 20 to 24 inclusive, the turning point being reached December 22; calling the eruptive period of Mokuaweoweo forty-eight days, from November 25 to January 11 inclusive, the middle day of the period, twenty-four days after the outbreak, was December 18–19. January 4, 1915, appears to have been the date of highest tide in Halemaumau, when the last overflows of the lake took place at an elevation 363 feet below the southeast rim of the pit; on January 13 the lake had fallen about thirty-five feet below this, or 398 feet below the rim.

Kilauea was intensely active and in general rising all through December, and in accordance with the measurements of preceding years it was fully expected at the Observatory that it would sink in January. The movements of the lava column, though as a whole lower, have been remarkably parallel to those of 1911–12, when also there was a maximum on January 4.

There was glow over Mokuaweoweo January 6, 1915, and a tuft of fume like white cotton appeared on the morning of January 7, apparently blowing away to the west. For the previous fortnight there had been no marked changes, except that a diffuse glow had appeared at night distinct from the light reflected from the obvious fume cloud, and frequently in the air around the fume column. This was attributed to atmospheric conditions. At and around 2 p. m. January 6, streamers of white cloud rose in tufts from the higher cone region on the northeast slope of Mauna Loa, quickly disappearing and having no resemblance in color to the fume. On January 7 between 1 and 2 p. m. the same thing happened again, mostly above the snow-line, along the northeast cone line, and at one time over Mokuaweoweo itself, the color of the white tufts being quite distinct from blue fume against which they showed. At 3:30 p. m. these white jets were still at work near the two upper cones where similar jets have been seen

Fig. 13.



from time to time during the past three years. January 9 there was a strong column of fume rising high and bending southward, and in the evening bright glow with some visible fume, blowing to the southwest.

January 10 at the Observatory the weather was brilliant with strong northeast wind. The fume was seen in Kona, but day and night there was no trace of fume or glow seen from the Observatory at Kilauea. No fume or glow was seen thereafter, nor was any reported from other points. On January 14 at 8 a. m. the weather was calm with the Kilauea fume rising high and spreading into a mushroom. There was no evidence of a high wind current which might blow the fume on Mauna Loa away. With clear seeing and powerful field glasses not the slightest trace of fume was detected over Mokuaweoweo.

From January to June 1915 inclusive, Mauna Loa has been under incessant inspection from a distance and no trace of fume or glow recurred until after the summer solstice. With the migration of the sunset position back of Mauna Loa thin but definite fume was detected from the Observatory by Mr. H. O. Wood at sundown July 10, 11 and 13, 1915, rising, or standing, above Mokuaweoweo. Shortly after noon July 14 several persons saw fumes above the summit. No glow has been certainly seen at night, though one inexperienced observer reported glow of short duration 11.30 p. m. July 10. Whether this episode is a slight revival of gas activity or merely exceptional seeing conditions is not clear. Kilauea lava had risen slightly in June.

It may be concluded that the outbreak of 1914–15 was a preliminary summit ebullition of the same type as the preliminary outbreaks of previous eruptive periods; those of 1870, 1872, 1873, 1874, and 1875, and 1876 anticipated the submarine flow of 1877 at Kealakekua; that of May 1880 heralded the great Hilo flow of 1880–81; those of 1892 and 1896 preceded the flow from the Dewey Crater July 4, 1899; the summit action of October–November 1903 preceded the Kahuku flow of 1907.

The phenomenon in this eruption which most impressed the writer, and which seemed contrary to some of the early accounts of the Mauna Loa lava fountains, notably those of William Lowthian Green, was the extraordinarily light and foamy character of the spurts seen above the large fountain on December 15 in Mokuaweoweo. The quick chilling and change of color in the upper part of the fountain through cherry-red and purple to black, and the blowing away of the fragments like pieces of burnt paper, was utterly unlike the heavy splashes of orange-red melt seen in the fountains of Kilauea. The material of consolidation of this eruption of 1914 will probably prove to be in part a light limu or what Dana called "thread-lace scoria." Such material, often sherry-colored and with iridescent surfaces, the writer collected about hot cracks near Mokuaweoweo in 1912, this being presumably the summit product of the 1903–1907 activities. There is much limu occurring as small lapilli about the summit area, showing that this material was blown about during recent eruptions, and the central cones in the crater, built in 1903, are largely of pumiceous material.

The occurrence of gas-impelled and gas-heated fountains of lava foam as the initial manifestation of a rising lava column at the summit of Mauna Loa, 10,000 feet higher than the vent of Kilauea, is more compatible with the possibility of a subterranean connection between the conduits of the two volcanoes than would be the case if the Mauna Loa fountains were jets of heavy melt without any sign of gas or flame. It may well be that with the expansion, escape and oxidation of the gases rising as bubbles through the lava, a subterranean cooling and congealing effect determines for the time being the duration of the preliminary phase. There follows a term of accumulation accompanied by some change of state which is less frothy and the final lava flow relieves the accumulated stress and ushers in a repose period.

The question of sympathy with Kilauea must still be considered an open one. In the long and large, the activities of Kilauea have shown tendency to alternate with the eruptive periods of Mauna Loa, this being especially striking since 1887. The repose period 1908–1913 of Mauna Loa was a time of rise, culmination and fall in Kilauea. In 1913–1914 Kilauea lava subsided to smoky depths for a year and then came the Mauna Loa outbreak. With this outbreak, however, the Kilauea column gradually rose to a relatively low culmination coincident with the month of Mauna Loa activity and thereafter it subsided, but has slightly revived with the solstice of June, 1915. The writer inclines to the belief that future research will demonstrate a complicated sympathy of alternation between the two volcanoes dependent upon gas release at one vent impoverishing the other. But the response is not instantaneous and phenomena of what may be called back-kick are to be looked for. Something of this kind may explain the rise of Kilauea in 1914–15, if that rise proves to be temporary.

Volcano Observatory, Hawaii.

Art. XLIV.—*Decomposition of Mineral Sulphides and Sulpho-Salts by Thionyl Chloride;* by H. B. North and C. B. Conover.

In another journal* the authors have recently described an investigation of the action of thionyl chloride on sulphides, the study being limited entirely to compounds prepared in the laboratory by precipitation or by fusion. Reaction was found to proceed according to the following general equation in which M represents a divalent element:

$$MS + 2SOCl_2 = MCl_2 + SO_2 + S_2Cl_2.$$

Deviation from this was found only in two or three cases in which oxidation as well as chlorination took place.

Inasmuch as minerals are frequently less readily attacked by reagents than are artificially prepared compounds, the study has been continued to the reaction of thionyl chloride on a number of mineral sulphides and sulpho-salts.

The minerals used were carefully selected specimens. The fragments chosen were powdered in an agate mortar, the powder dried at 110° and preserved in tightly stoppered tubes. The reactions were carried out in sealed glass tubes, about a gram of the powdered mineral and an excess of thionyl chloride being heated together in each experiment. The temperature employed was 150–175° C.

When reaction appeared to be complete, the tubes were opened, the solid contents well washed with carbon disulphide, dried and analyzed. Sulphur dioxide and sulphur monochloride were found to be present in every experiment in which reaction took place. In nearly all cases a small amount of white insoluble matter remained when the sample taken for analysis was dissolved. This proved to be silica. In the three quantitative experiments this silica was weighed and the weight deducted from that of the sample taken.

Galena.—Thionyl chloride did not react with galena when the two were brought together at the ordinary temperature. When heated at 150° the solid contents of the tube gradually whitened. Reaction appeared to be complete after 40 hours. Analysis of the white solid proved it to consist almost entirely of lead chloride with a trace of ferric chloride. Reaction takes place as follows:

$$PbS + 2SOCl_2 = PbCl_2 + SO_2 + S_2Cl_2.$$

Pyrites.—Pyrites and thionyl chloride did not react in the cold, but at 150° reaction took place readily with the formation

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* Journal of the American Chemical Society, Nov. 1915.

of beautiful hexagonal green crystals of ferric chloride. Reaction undoubtedly follows the equation:

$$6FeS_2 + 20SOCl_2 = 6FeCl_3 + 10SO_2 + 11S_2Cl_2.$$

Cinnabar.—The reagent appeared to be without effect on cinnabar at the ordinary temperature, but reaction was complete after a few hours heating at 150–175°. The solid product formed consisted of a mass of white needle crystals which upon analysis were found to be mercuric chloride. Reaction takes place according to the equation:

$$HgS + 2SOCl_2 = HgCl_2 + SO_2 + S_2Cl_2.$$

In addition to the above mentioned experiments in which the product was analyzed quantitatively, the following tests were made merely to ascertain whether decomposition of the mineral results from heating with thionyl chloride.

Pyrargyrite.—Decomposition took place slowly, but a very appreciable change was noticed after 48 hours. After heating for several days reaction appeared to be complete and the solid matter in the tube was found to consist entirely of chlorides.

Proustite.—Reaction proceeded much more slowly than with pyrargyrite. After 48 hours only a slight change had taken place, as was indicated by the appearance as well as by qualitative tests. Thionyl chloride decomposes proustite with great difficulty.

Argentite.—The tube containing thionyl chloride and argentite was heated for several days without the slightest change in the appearance of the contents. Qualitative tests failed to show even the slightest traces of silver chloride. The results of this experiment are interesting inasmuch as the authors have previously shown* that the artificially prepared silver sulphide is decomposed readily by thionyl chloride giving silver chloride.

Covellite.—This mineral was completely decomposed by thionyl chloride within 48 hours.

Boulangerite.—Boulangerite reacted readily with the reagent, the color of the powder becoming white within a few hours. Qualitative tests showed the mineral to be completely decomposed.

Enargite.—Decomposition of enargite took place rapidly, as was shown by the production of brown anhydrous cupric chloride.

Marcasite.—Specimens of marcasite from two widely separated localities were employed. In both cases decomposition took place completely within a few hours, each yielding the green crystals of ferric chloride.

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* Loc. cit.

Molybdenite and Cobaltite.—These two minerals were not affected by the reagent even after heating for several days.

Orpiment and Realgar.—These minerals were completely dissolved by thionyl chloride within a few hours. No attempt was made to identify the arsenic trichloride formed inasmuch as it is a liquid and difficult to separate from thionyl chloride. Reaction had certainly taken place, as was shown by the sulphur dioxide and sulphur monochloride which were easily identified in the tubes.

Stibnite.—This mineral likewise was completely dissolved by the reagent, undoubtedly with the formation of antimony pentachloride. The tube contained sulphur dioxide and sulphur monochloride, leaving no doubt that reaction had taken place.

Sphalerite.—No visible change took place in the sphalerite, but after heating for several days the solid contents of the tube were shown by analysis to be zinc chloride. Reaction therefore had taken place.

Tetrahedrite.—Tetrahedrite was found to react slowly with the formation of anhydrous cupric chloride. The antimony and sulphur went entirely into solution.

Arsenopyrite.—Arsenopyrite was completely decomposed after heating for a few hours, the arsenic going entirely into solution while the iron remained in the form of crystallized ferric chloride.

Résumé.—Of the minerals studied, the only simple sulphides which do not react with thionyl chloride are argentite and molybdenite. In general the more complex mineral sulphides and sulph-arsenides are likewise decomposed by the reagent though the time required for complete reaction varies greatly.

Rutgers College, New Brunswick, N. J.

Art. XLV.—*On Simple and Mixed Alkyl Phosphates*; by W. A. Drushel.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—cclxxvi.]

When a sodium alcoholate free from the alcohol is treated with the theoretical amount of phosphorus oxychloride at room temperature in the presence of ether a good yield of the corresponding trialkyl phosphate is obtained.* By means of this reaction Lossen and Köhler† in 1891 prepared trimethyl phosphate, triethyl phosphate, and from these esters they prepared by a method to be described the mixed esters, dimethyl-ethyl phosphate and methyl-diethyl phosphate. They studied these simple and mixed alkyl phosphates with special reference to their behavior toward barium hydroxide at room temperature. From their observations they drew the following conclusions:

(1) That the esters of phosphoric acid are far more stable than the esters of organic acids toward aqueous barium hydroxide.

(2) That the salts of dialkyl phosphoric acids are much more stable than the trialkyl phosphates.

(3) That more than one alkyl group of a trialkyl phosphate may be hydrolyzed off only with the greatest difficulty, if at all.

(4) That the decomposition of mixed alkyl phosphates by aqueous barium hydroxide proceeds in an unusual manner, in that in mixed alkyl phosphates one alkyl group is hydrolyzed off to the exclusion of the other. Apparently the same methyl-ethyl-barium phosphate was obtained by these investigators by the action of barium hydroxide upon both methyl-diethyl phosphate and dimethyl-ethyl phosphate.

The purpose of the present investigation was to prepare a larger number of the simple and mixed esters of orthophosphoric acid, to study their properties and rates of hydrolysis in decinormal hydrochloric acid, and to examine the validity of Lossen and Köhler's fourth conclusion since this conclusion is contrary to the rule observed in the case of esters of dibasic and polybasic organic acids. In general the methods described by Lossen and Köhler were used in the preparation of the esters prepared and studied in this investigation. For the preparation of the simple esters sodium alcoholate in each case was prepared by dissolving a weighed amount of pure metallic sodium in a sufficient excess of the desired alcohol. After the sodium was completely used up the excess of alcohol was distilled off in an oil bath, heating the bath finally at 180° as

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*Limpricht, Ann. Chem. Pharm., cxxxiv, 347.

† Ann. Chem. Pharm., cclxii, 209–14.

long as any alcohol distilled over. The residue of sodium alcoholate was cooled, covered with absolute ether and treated with the theoretical amount of phosphorus oxychloride, diluted with an equal volume of absolute ether, by adding the diluted phosphorus oxychloride in small portions through a reflux condenser, taking care to keep the reaction mixture cool by immersing the flask in cold water. At the conclusion of the reaction the residue of sodium chloride was filtered off, the filtrate distilled on a warm water bath to remove the ether, and the residue subjected to fractional distillation. The fractionation was made at diminished pressure for all of the esters except trimethyl phosphate, triethyl phosphate and dimethylethyl phosphate. These three esters were distilled at ordinary pressure without decomposition.

The mixed alkyl phosphates were prepared from the simple esters by making successively the barium salts by the action of aqueous barium hydroxide upon the simple esters at room temperature, the free dialkyl phosphoric acids by the action of sulphuric acid upon the purified barium salts, the silver salts of the dialkyl phosphoric acids by the neutralization of these acids with silver oxide, and finally the mixed alkyl phosphates from the silver salts by the action of the appropriate alkyl iodides in ethereal solution. The silver iodide was then filtered off, the ether distilled off from the filtrate and the residue fractionally distilled, generally under diminished pressure. The boiling points of these simple and mixed esters at diminished or ordinary pressure, their densities at 0° and at room temperature and their solubilities in water at room temperature were determined, and are recorded in Table I. According to Winssinger's* observation the tripropyl phosphate decomposes when boiled even in vacuo. In order to test the correctness of this observation this ester was redistilled four times at a pressure of 15^{mm} without any change in the boiling point observed in the first distillation and without any other evidence of the decomposition of the ester. The isobutyl ester was likewise redistilled at 15^{mm} without any evidence of decomposition.

In order to determine whether one alkyl group in mixed alkyl phosphates is hydrolyzed to the exclusion of the other alkyl group contrary to the rule in the case of esters of organic acid, the barium salts of a number of simple and mixed alkyl phosphates were prepared by the action of a slight excess of barium hydroxide upon the esters in aqueous solution either at room temperature or upon the steam bath, were purified and analyzed for barium, obtaining the results recorded in Table II. It is to be observed that when barium hydroxide reacts with simple alkyl phosphates the barium content of the result-

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* Bull. soc. chim., xlviii, 111.

TABLE I.

Esters	Boiling point	Pressure in mm.	Density		Solubility in water at 25°
			0°	22°	
Me_3PO_4**	197	760	1·218	1·200	1 : 1
Et_3PO_4	215	760	1·071	1·056	1 : 1
Pr_3PO_4	131	15	1·025	1·007	1 : 155
$Isobu_3PO_4$	152	15	0·978	0·965	1 : over 1000
Me_2EtPO_4	203	760	1·176	1·161	1 : 1
Me_2PrPO_4	116	15	1·195	1·180	1 : 1
$MePr_2PO_4$	129	20	1·077	1·059	1 : 22
Et_2PrPO_4	130	20	1·098	1·077	1 : 1
$EtPr_2PO_4$	145	20	1·046	1·025	1 : 45

** Me denotes methyl; Et, ethyl, etc.

ing salts agrees well with the calculated amount, and that when barium hydroxide under the same conditions acts upon mixed alkyl phosphates in no case does the amount of barium found in the resulting salts agree with the amount calculated for the theory that only one of the two different alkyl groups is hydrolyzed off to the exclusion of the other. It is safe to conclude, contrary to Lossen and Köhler's theory, that in mixed alkyl phosphates barium hydroxide does not remove one of the different alkyl groups to the exclusion of the other and that, although one alkyl group may be more readily attacked than the other of two different alkyl groups, the reaction does not by any means go wholly in that direction.

The reactions involved in the preparation and hydrolysis of alkyl phosphates may be briefly summed up in the following equations, where R denotes an alkyl group and R′ a different alkyl group:

$2ROH + 2Na \rightarrow 2RONa + H_2$,
$3RONa + POCl_3 \rightarrow R_3PO_4 + 3NaCl$,
$2R_3PO_4 + BaO_2H_2 \rightarrow BaR_4(PO_4)_2 + 2ROH$,
(also to a very slight extent, $R_3PO_4 + BaO_2H_2 \rightarrow BaRPO_4$* + $2ROH$),
$BaR_4(PO_4)_2 + H_2SO_4 \rightarrow 2HR_2PO_4 + BaSO_4$,
$2HR_2PO_4 + Ag_2O \rightarrow 2AgR_2PO_4 + H_2O$,
$AgR_2PO_4 + R'I \rightarrow R_2R'PO_4 + AgI$,
$2R_2R'PO_4 + BaO_2H_2 \rightarrow BaR_2R'_2(PO_4)_2 + 2H_2O$,
also $2R_2R'PO_4 + BaO_2H_2 \rightarrow BaR_4(PO_4)_2 + 2H_2O$.
$R_3PO_4 + HOH + HCl \rightarrow HR_2PO_4 + ROH + HCl$ (First stage),
$HR_2PO_4 + HOH + HCl \rightarrow H_2RPO_4 + ROH + HCl$ (Second stage),
$H_2RPO_4 + HOH + HCl \rightarrow H_3PO_4 + ROH + HCl$ (Final stage).

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* This salt being insoluble is readily removed by filtration.

$R_2R'PO_4 + HOH + HCl \rightarrow HRR'PO_4 + ROH + HCl$ (also $R_2R'PO_4 + HOH + HCl \rightarrow HR_2PO_4 + R'OH + HCl$), (First stage); similarly for the second and final stages. In each case the first alkyl group is hydrolyzed off more easily than the second and third groups, which is in agreement with Lossen and Köhler's observation for the saponification of these esters by barium hydroxide at room temperature.

TABLE II.

Barium salts of dialkyl phosphoric acids prepared and analyzed for barium.

Esters and Salts		Per cent. of barium		
		found	theory	
$Ba(Me_2PO_4)_2$	*	35·2	35·4	
		35·3		
$Ba(Et_2PO_4)_2$	r	31·2	30·7	
		31·3		
$Ba(MeEtPO_4)_2$	rI	34·0	33·0	Salt probably contained some
from	r	34·1		$BaMe_4(PO_4)_2$.
Me_2EtPO_4.	rII	34·1	35·4	calculated for $BaMe_4(PO_4)_2$.
$Ba(MePrPO_4)_2$	rI	32·0	30 6	Salt probably contained some
from	rII	32·1		$BaMe_4(PO_4)_2$.
Me_2PrPO_4,	s	34·1		
from	sI	28·8	27·5	calculated for $BaPr_4(PO_4)_2$.
$MePr_2PO_4$.	sII	28·9		Salt probably contained some
				$BaPr_4(PO_4)_2$.
$Ba(EtPrPO_4)_2$	s	31·6	29·1	Salt probably contained some
from		31·5		$BaEt_4(PO_4)_2$.
Et_2PrPO_4,				
from	r	27·7		Probably chiefly $BaPr_4(PO_4)_2$
$EtPr_2PO_4$.		27·7		formed.

* *r*, Saponification was made at room temperature; *s*, on the steam bath.

The acid hydrolysis of the esters recorded in Table III was made in flasks contained in a boiling water bath especially constructed for the purpose and fitted with a reflux condenser. Decinormal hydrochloric acid was used as the hydrolytic agent and the course of the reaction was followed in the usual way by making titrations with decinormal barium hydroxide, using phenolphthalein as an indicator. In each case weighed amounts of ester were used, making the concentration of ester in the reaction mixture initially decinormal. Since the end-point of the primary hydrolysis stage could not be determined by titration on account of the interference of the secondary and tertiary stages, it was calculated in each case from the weight of ester taken. However, since the secondary and tertiary hydrolysis products form insoluble barium salts, it was possible to observe directly how far the titrations furnished reliable data for calculating the velocity constants for the primary hydrolysis stage. The constants recorded in Table III represent only the primary hydrolysis stage, the latter constants in some cases being perhaps slightly influenced by the secondary reaction. In calculating the constants the reaction was considered of the first order and no account was taken of the possible hydrolytic effect of the very weak dialkyl phosphoric acids set free in the primary hydrolysis stage. The acid hydrolysis was first attempted at 25° but was found to proceed so slowly as to make it impracticable at this temperature. A fifth normal solution of trimethyl phosphate in decinormal hydrochloric acid was allowed to stand for thirty-two days at 22° to 25° with an increase of only five per cent in the total acidity of the reaction mixture, and the triethyl ester hydrolyses only about one-fourth as fast. The measurements were therefore made at 100°.

TABLE III.

Hydrolysis of alkyl phosphates in N/10 HCl at 100°.

Me_3PO_4	Et_3PO_4	Me_2EtPO_4	Me_2PrPO_4	Et_2PrPO_4	
				I	II
600 min.	2100 min.	830 min.	700 min.	1770 min.	760 min.
10^5K	10^5K	10^5K	10^5K	10^5K	10^5K
209	50·9	182	203	62·1	60·9
215	51·8	184	209	59·2	61·5
224	50·1	189	207	61·1	59·5
223	55·3	183	200	61·6	61·2
225	55·2	184	199	62·1	
	55·4	189	198	61·9	
219	53·7	185	202	61·3	60·8

In this table the ranges of time in minutes through which the titrations were used in the calculation of the constants are given at the top of the columns. In this table of constants the very marked difference in the resistance to hydrolysis of the three alkyl groups, methyl, ethyl and propyl, is noteworthy. The distinct effect of the single alkyl group in the mixed esters upon the rate of hydrolysis is also to be observed. According to Lossen and Köhler's theory, in mixed alkyl phosphates the alkyl group occurring twice is saponified to the exclusion of the single alkyl group. In order to explain the velocity constants for the mixed esters on this theory it would be necessary to assume that the presence of the single alkyl group increases the resistance to hydrolysis of the alkyl group occurring twice in the ester. The effect observed is more simply explained by assuming that the hydrolysis is not confined to the alkyl group which occurs twice in the molecule but that in at least some of the molecules the single alkyl group is hydrolyzed off, yielding in the hydrolysis products acids of both types $HRR'PO_4$ and HR_2PO_4. This view is in agreement with the results obtained in the barium hydroxide saponification shown in Table II.

Conclusions:—

1. Both the simple and mixed alkyl phosphates are very stable at room temperature even in decinormal hydrochloric acid, but are rapidly saponified by barium hydroxide.
2. All of the alkyl groups are hydrolyzable, although the first group is much more easily attacked than the second and third.
3. In mixed alkyl phosphates the alkyl group which occurs twice is not hydrolyzed to the exclusion of the single group, but on the contrary the hydrolysis product contains both types of dialkyl phosphoric acids, $HRR'PO_4$ and HR_2PO_4, with the first type probably very largely in excess of the second type.
4. Tripropyl phosphate and triisobutyl phosphate are both distillable in vacuo without decomposition.

ART. XLVI.—*Two New Fresh-water Gastropods from the Mesozoic of Arizona*; by W. I. ROBINSON.[*]

IN the summer of 1914, Professor H. E. Gregory of Yale University collected an abundance of fresh-water gastropods in northeastern Arizona. They are pseudomorphs of SiO_2, but occasionally preserving patches of the external surface markings. They vary much in size and proportions, but are all referable to two species, *Valvata gregorii*, sp. nov., and *Limnea hopii*, sp. nov. The former species was also collected by Professor Gregory in 1913 from the "Painted Desert beds," chiefly Jurassic, about four miles northeast of Black Falls, Arizona. Both species are closely allied to forms described by C. A. White,[†] from beds now referred to the Morrison formation and assigned by him to the Jurassic.

In the collection of 1914, Professor Gregory also found a number of *Unio* fragments, apparently in the top of the Triassic of the Moenkopi Valley about six miles below the bridge on the Tuba-Flagstaff road. They are too fragmentary for specific determination, but Doctor T. W. Stanton, of Washington, D. C., to whom the fossils were submitted for confirmation of my work, states that they resemble *Unio cristonensis* Meek, a Triassic form.

Valvata gregorii, sp. nov. (Fig. 1, *d* and *e*.)

Shell sub-globose: from two to three evenly rounded whorls; the first two raised in a low spire, the last increasing rapidly in size and coiling obliquely to the planes of the other two. Umbilicus small, but well-defined. Peristome entire; inner lip somewhat reflexed. Interior surface with transverse growth lines. Exterior showing in rare cases several longitudinal ridges and grooves. Size and proportions variable.

Smallest specimen,	height	4^{mm},	width	6^{mm}
Medium	"	10·5 "	"	11 "
Largest	"	16·5 "	"	18 "

This species resembles *Valvata scabrida* Meek and Hayden,[‡] but differs from it in having fewer whorls, and a different manner of coiling.

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[*] Published by permission of the Director of the U. S. Geological Survey.

[†] White, C. A., On the Fresh-water Invertebrates of the North American Jurassic, Bull. U. S. Geol. Surv., No. 29, 1886.

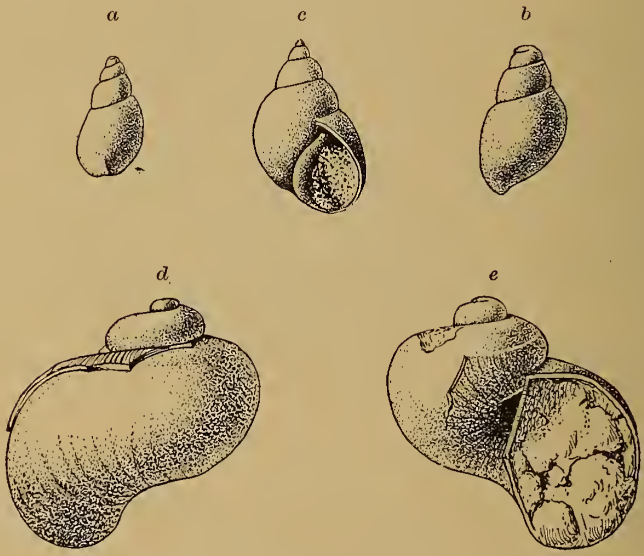
[‡] Paleontology of the Upper Missouri, p. 113, pl. iv, figs. 2a, 2b, 1865.

Found in the "Painted Desert beds" of northeastern Arizona. The species is named after Professor Gregory, who collected the specimens.

Limnea hopii, sp. nov. (Fig. 1, *a*, *b* and *c*.)

Shell small, with moderately high spire. Whorls three to five, the last ventricose and having a height equal to that of the others combined. Aperture sub-oval. External surface not seen. Size and proportions variable.

Fig. 1.



Smallest	specimen,	height	5^{mm},	width,	$3·5^{mm}$
Medium	"	"	9 "	"	5·5 "
Largest	"	"	12 "	"	8·0 "

These shells closely resemble *L. ativuncula* White,* but differ from it in having fewer whorls and in being broader proportionately. The spire of *L. ativuncula* is slightly more attenuated than that of *L. hopii*.

Found in the "Painted Desert beds" of northeastern Arizona. Specific name after an Arizona tribe of Indians.

Both Limnea and Valvata are represented by numerous species from the late Mesozoic to Recent time. As no undoubted

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* White, C. A., op. cit., p. 20, pl. iv, figs. 10 and 11.

representative of these genera has been found in beds earlier than late Jurassic, and as the two species described above are closely related to late Mesozoic species, the fossil evidence indicates that the time of the deposition of the new forms was Jurassic and probably middle or late Jurassic. A discussion of the stratigraphy of these beds will be published by Professor H. E. Gregory for the United States Geological Survey.

EXPLANATION OF FIGURES.

FIG. 1 *a–c*. *Limnea hopii*, sp. nov.
  a and *b*. Two individuals differing slightly in outline from the type specimen (*c*), twice natural size.
  c. Apertural view of the holotype, three times natural size.
FIG. 1 *d* and *e*. *Valvata gregorii*, sp. nov. Two views of the holotype, twice natural size.

ART. XLVII.—*The Ordovician Cynthiana Formation*; by ARTHUR M. MILLER.

As defined by the writer in this paper, the Cynthiana formation of the Cincinnatian series consists of those limestones and shales 40–90 feet in thickness which overlie the Trenton limestone as defined by William Linney in his report on Garrard County, Ky.* That author placed as the top member of the Trenton in Mercer and Garrard Counties the "Upper Birdseye Limestone," which we now know as the Perryville. Linney considered all of the "Lower Silurian" beds above this horizon in Kentucky as "Hudson," and divided them into three parts,—Lower, Middle, and Upper—each with a thickness of about 200 feet. As the upper limit of the Lower Hudson he selected certain layers of "wave-marked limestone" which occur just below sandy beds—the "siliceous mudstone" of Owen.

M. R. Campbell in his report on the Richmond Quadrangle † accepted the definition of these beds as given by Linney, and applied to them the formation name of "Winchester Limestone." His estimate of their thickness within the limits of the Quadrangle was 225 feet.

The writer of this paper, in a report on the Lead and Zinc Bearing Formation of Central Kentucky, ‡ in the manuscript identified the Cynthiana formation with the Catheys of Ten-

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* Geol. Surv. Ky., 1882.

† U. S. Geol. Surv., 1898.

‡ Geol. Surv. Ky., 1905.

nessee (to which in part it belongs), but subsequently corrected this in the proof to "Winchester." However, a section on page 21 and the map accompanying the report had at that time already been engraved and retains the name "Catheys." In the report, however, the name Cynthiana was limited to those lower "rubbly" limestones of Linney's Lower Hudson which in the area under discussion attained a thickness of 40–60 feet.

The reason for including under the name "Winchester" less than was embraced by Linney or Campbell under that name was the result of investigations carried on by the writer alone, and also in conjunction with Foerste and Nickles, which led to the tracing of these beds northward to the Ohio River at Cincinnati and Moscow and to the discovery that the Eden of Orton included the upper portion of the Winchester beds. The first placing of the Winchester in the Cincinnatian was in the publication by J. M. Nickles entitled The Upper Ordovician Rocks of Kentucky and their Bryozoa.* Subsequently, Foerste, in the "Table of Paleozoic Formation" for Kentucky in his Silurian, Devonian and Irvine Formations of East-Central Kentucky,† showed the true equivalence of Winchester and used the name "Cynthiana" for that portion of it lying below the Eden or below the Fulton bed at Ludlow which had been provisionally correlated with the Utica of New York. He divided the Cynthiana in ascending order into the Greendale and Point Pleasant.

The writer of the present paper, finding practically everywhere in North Central Kentucky towards the top of the Cynthiana, wave-marked crinoidal limestone layers made up of the stem plates and occasionally of portions of the calyces of the crinoid *Ectenocrinus simplex*, also fragments of the shells of the brachiopod *Plectambonites rugosus* James (*sericeus* of Meek, not Hall) and of the trilobite, *Trinucleus concentricus*, drew the line between the Cynthiana and Eden at the base of these crinoidal layers. About ten feet above the base of these layers perfect shells of *Plectambonites rugosus* become abundant and range through the remainder of the Eden; *Ectenocrinus simplex* has the same range. The shaly character of the Eden also becomes apparent at this horizon. It was the presence of these shales which makes appropriate Orton's name "Eden Shales." A recent joint examination in the field by E. O. Ulrich and the writer has disclosed that the former has been drawing the line between the Cynthiana and the Eden at this horizon, about 10 feet above where the writer has been drawing it, and further that along the river front in the old Fulton Ward of Cincinnati the bed of clay

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* Ky. Geol. Surv., 1905.

† Ky. Geol. Surv., 1906.

shale 4–5 feet thick, and known as the "Fulton" (because it has *Triarthus becki*, it has been correlated with the Utica), actually belongs about 10 feet above the base of the Eden as identified by the latter.

It is also now evident that Professor Foerste in his classification of the Ordovician rocks of Ohio and Indiana* agrees with Ulrich in placing the Fulton immediately above these crinoidal layers. At the same time he expresses doubt as to these 4–5 feet of shale with *Triarthus becki* being the equivalent of the whole of the Utica further north, in which view the writer concurs.

The difference for mapping purposes is not appreciable if this lower 10 feet of the Eden be included in the Cynthiana. They appear however to the writer, on account of the fragmental condition of the contained Eden fossils (*Plectambonites rugosus* and *Ectenocrinus simplex*), to have been formed by the working over of basal beds already laid down at the beginning of a new cycle of deposition, and to belong properly on the Eden side of the hiatus which everywhere in North Central Kentucky marks the juncture of the Cynthiana and Eden. We should place therefore only the lower 40 feet of the limestone beneath the "wave layers" as exposed at Cincinnati and Covington definitely in the Cynthiana.

Further up the Ohio River from Cincinnati, at Point Pleasant on the Ohio side, and on the Kentucky side opposite New Richmond and Moscow, and at Carntown and Foster, Ky., a greater thickness of beds is exposed below the Fulton shale than at Cincinnati,—seeming to indicate that the axis of the Cincinnati Anticline is trenched by the Ohio River east of Cincinnati. Professor Ulrich would explain the phenomenon by the trenching of the eastward flank of a northward plunging anticline at a point further south, due to the general northward course of the Ohio River in this stretch. The observations of the writer, however, indicate that the northward plunge of the anticline is too gentle to admit of this explanation.

At Point Pleasant, Professor Foerste begins the Fulton shale 113 feet above the river. In some places where the lower layers are exposed they contain the brachiopod *Dalmanella bassleri* and the bryozoan *Prasopora simulatrix*, which indicate the Wilmore bed of the Lexington (Trenton) limestone.

There is an unexposed interval in all these sections between the Lexington limestone and some distance up in the Cynthiana; so it is impossible to say on what bed of the Lexington in the Ohio River exposures the Cynthiana rests.

Conditions are similar along the Licking River, which roughly parallels the Ohio to the southwestward. The still older

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* Science, Aug. 4, 1905.

Wilmore is exposed at lowest levels as far north as Butler with an unexposed interval representing the Bigby next above. (It would appear from latest investigations that Bigby should be made to include all of the Lexington between the Wilmore and Perryville.) The interval however is not sufficient to admit of the entire thickness that this formation attains in the region around Lexington to the south.

At the Lower Blue Licks the top of the Lexington (Trenton) is about 55 feet above the river and is very sparingly fossiliferous. However the presence of *Rhynchotrema inæquivalve*, *Hindia parva* and a Lexington type of *Lophospira* indicates that the Woodburn bed of the Bigby is present this far north in Kentucky. The Cynthiana follows immediately above and is here 85 feet thick with the typical lithology and fossils of this formation as developed on the eastern flank of the Cincinnati Anticline. The usual wave-marked crinoidal limestone appears at the top. West of Blue Licks on the South Fork of the Licking, in the vicinity of Cynthiana, the section is similar: —the Cynthiana rests on limestones with *Rynchotrema inæquivalve* that are undoubtedly of Bigby age.

Further south in the vicinity of Paris, but in the same drainage area, the usual relation of the Cynthiana to upper and lower formations prevails; but at one locality, about one mile northeast of Paris, a small patch of the Perryville bed of the Lexington (Trenton) appears on top of the Woodburn member of the Bigby—the only known occurrence of this bed on the eastern side of the Cincinnati Anticline.

Still further south, in the Kentucky River drainage, and in the vicinity of Lexington, on and near the crest of the Cincinnati Anticline, the Cynthiana has decreased in thickness to about 40 feet and every contact with the underlying formation shows that it rests on the Woodburn member of the Lexington. However in the soil of some places are found traces of a gastropod—chert, which indicates that at least the lowest portion of the Perryville (also of the Lexington formation)—the Faulconer—was present and that over it the deposition of the Cynthiana transgressed.

West of Lexington, beyond the middle and western portion of Woodford County, the two lower members of the Perryville —the Faulconer and Salvisa—are generally present and the Cynthiana rest on the last named member. In Franklin County in the vicinity of Frankfort, these two members of the Perryville are also generally present and thicker than further east. Southward from Franklin County on the west side of the Cincinnati Anticline the Perryville thickens, and in Mercer County another member—the Cornishville—is added to the top, and it is upon it that the Cynthiana of the Cincinnatian series rests.

The writer is not equally familiar with the lower Ordovician section of the Nashville area in Tennessee, but a visit made to that region several years ago enables him to identify in the uppermost rocks within the limits of the city of Nashville typical Cynthiana as it is developed in Central Kentucky. Here it lies above the "Upper Dove Limestones" of Safford, which are undoubtedly the equivalent of the Salvisa of Kentucky.

It is therefore evident from the foregoing that structurally the Cynthiana is a well-defined member of the Cincinnatian series, and that it lies between two disconformities—the lower more marked than the upper. In its exposures in the Blue Grass areas of Kentucky and Tennessee it everywhere furnishes a soil of good quality but inferior to that resulting from the Lexington limestone. It is, however, much superior to that formed by the overlying Eden.

Faunally also it is distinct. The characteristic upper Lexington limestone (Bigby) brachiopods—*Rhynchotrema inæquivalve*, *Hebertella frankfortensis* (*borealis* of some authors)—do not pass up into it. A list of the most abundant fossils of the Cynthiana contains the following:

Corals
  Columnaria alveolata Hall (*stellata* of some authors).
Hydroids
  Selenopora irregularis Ulrich.
  Stromatocerium sp.?
Crinoids
  Glyptocrinus sp.? *Iocrinus subcrassus* M. & W., *Lichenocrinus crateriformis* Hall.
Bryozoans
  Aspidopora calycula James, *Ceramporella ohioensis* Nich. (doubtful identification), *Constellaria emaciata* U. & B., *Constellaria fischeri* Ulrich, *Crepipora spatiosa* Ulrich, *Eridotrypa briareus* Nich. (very characteristic of this formation), *E. mutabilis* Ulrich, *Escharopora ponderosa* Ulrich, *Heterotrypa parvulipora* U. & B., *Homotrypella norwoodi* Nickles, *Peronopora milleri* Nickles, *Petigopora* sp.?, *Prasopora* sp.?
Brachiopods
  Hebertella maria parkensis Foerste, *Hebertella sinuata* Hall, *Orthorhynchula linneyi* James, *Platystrophia colbyensis*? *Rafinesquina winchesterensis* Foerste, *Zygospira modesta* Hall.
Pelecypods
  Allonychia flanaganensis Foerste, *Byssonychia radiata* Hall, *Byssonychia intermedia* M. & W., *Ctenodonta* sp.? *Orthodesma* sp.?

		THE ORDOVICIAN IN KENTUCKY,			Thickness in feet.
Ordovician	Cincinnatian	Richmond		Saluda Limestone	40
				Whitewater Limestone	100
				Liberty Limestone	
				Waynesville Limestone	70
		Maysville		Arnheim Limestone	50
				Mt. Auburn Limestone	20
				Coryville Limestone	60
				Bellevue Limestone	20
				Fairmount Limestone	80
				Mt. Hope Limestone	50
		Eden		Paint Lick (Garrard) Sandstone	60
				Million Shale and Limestone	200
				Fulton Shale (Utica)	5
		Minor Disconformity.			10
	Mohawkian	Cynthiana		Point Pleasant Limestone	90
				Greendale Limestone	
		Disconformity			
		Lexington (Trenton)	Perryville	Cornishville Limestone	25
				Salvisa Limestone	
				Faulconer Limestone	
			Bigby	Woodburn Limestone	40
				Brannon Limestone	15
				Benson Limestone	70
				Wilmore Limestone	80
				Hermitage Limestone	30
				Curdsville Limestone	10
		Disconformity			
		High Bridge (Stones River)		Tyrone Limestone	90
				Oregon Limestone	25
				Camp Nelson Limestone	285
				Total	1525
		(Black River and Chazy)		Bottom not exposed.	

Gastropods
  Bellerophon sp.?, *Cyclonema varicosum* Hall (very characteristic of the formation), *Cyclora minuta* Hall, *Hormotoma gracilis* Hall, *Lophospira sumnerensis* (?) Saf.
Cephalopods
  Orthoceras sp.?
Trilobites
  Isotelus sp.?
  Calymmene senaria? Conrad.

As has been noted by Nickles and others, the foregoing assemblage of fossils strongly resembles the Fairmount fauna of the Mayville, though the species are mostly different. It is quite different from that of the intervening Eden.

By far the most characteristic single fossil of the Cynthiana is *Cyclonema varicosum.* It is an easily recognized fossil and present in every extensive exposure of the formation.

In New York and Canada the Utica shale follows the Trenton limestone abruptly with every evidence in those regions of an unrecorded time interval between.

It is the view of the writer that the Cynthiana partially fills this hiatus southward and that though necessarily transitional in its faunal aspects, it belongs more on the Cincinnatian than on the Mohawkian side of the line.

A revised table of formation for the Ordovician in Kentucky is here appended.

Note.—Since preparing the above for publication the writer has received a letter from Professor Ulrich, in which he gives an account of a recent examination of the Cynthiana northward from Lair Station to Claysville on the Licking River.

In this he correlates the lowest layers on the Licking at Claysville with these lowest layers on the Ohio River at Carntown and Foster and places these not in the Wilmore, but in the lower Cynthiana. With the identification of these beds as Cynthiana the writer cannot concur.

University of Kentucky,
    Lexington, Ky.

SCIENTIFIC INTELLIGENCE.

I. CHEMISTRY AND PHYSICS.

1. *Annual Report of the International Committee on Atomic Weights.*—At the meeting of the International Congress of Applied Chemistry in 1912 a resolution was passed favoring delay in changes in the table of atomic weights. In accordance with the desire so expressed no changes have since been made, but several now seem necessary to the committee. These changes are small and relate to C, S, He, Sn, Pb, Ra, Yt, Pr, Yb, Lu and U. The changes made in the more important cases are as follows :

	Carbon	Sulphur	Tin	Lead	Uranium
Previous	12·00	32·07	119·0	207·10	238·5
New, "1916".	12·005	32·06	118·7	207·20	238·2

These changes will have but little influence upon ordinary calculations. For instance, the change will give 27·28 instead of 27·27 as the percentage of carbon in CO_2, and it will give 78·77 instead of 78·81 as the percentage of tin in SnO_2. H. L. W.

2. *The Analysis of the Non-Ferrous Metals*, by FRED IBBOTSON and LESLIE AITCHISON. 8vo, pp. 230. London, 1915 (Longmans, Green and Co.).—The aim of this book is to present methods of analysis in which either accuracy and convenience or accuracy and speed are combined. It gives a general discussion of the apparatus and methods of electrolytic analysis as well as a general presentation of the effects of temperature and varying amounts of hydrochloric acid upon precipitations with hydrogen sulphide. Various methods are described for the determination of lead, copper, bismuth, antimony, tin, arsenic, aluminium, chromium, nickel, cobalt, and zinc, and finally the analysis of commercial alloys is discussed. The book is an excellent one, being well written and giving the best modern methods, and there is no doubt that many analysts may obtain much useful information from it. The authors do not consider the work complete or final, and hence it is to be expected that a few good methods extensively used by American chemists are not included. It may be mentioned as a matter of minor importance that the authors adhere to the old opinion that copper sulphide must be washed with cold water containing hydrogen sulphide so that it will not "oxidize" and pass into the filtrate, whereas, it is a fact that this precipitate can be washed with the greatest ease with hot water. The supposed oxidation when cold water is used is evidently due to the formation of colloidal copper sulphide which is not formed at all when hot water is used. H. L. W.

3. *A Course in Quantitative Chemical Analysis*; by NICHOLAS KNIGHT. 12mo, pp. 153. New York and Chicago, 1915 (The A. S. Barnes Company).—This book appears to be a very unsat-

isfactory one. The methods described in it are frequently poorly chosen or bad. Some of them are absolutely wrong. The most astonishing thing of this kind that has been noticed is the method given for the determination of the principal constituents of apatite. The substance is to be placed in a porcelain evaporating dish, nitric acid added and the liquid evaporated to dryness, and so on, in order to determine silica and the other things. The interfering effect of the fluorine in forming silicon fluoride and in dissolving material from the porcelain dish is entirely overlooked, although a method is given for determining fluorine in the mineral. This is practically the method of Berzelius, but even here the fatal error is made of not mentioning the addition of silica (when much of it is not present) before fusion with sodium carbonate. H. L. W.

4. *Household Chemistry for the Use of Students in Household Arts;* by Hermann T. Vulté. 12mo, pp. 254. Easton, Pa., 1915 (The Chemical Publishing Company).—This book gives a large number of experiments to be carried out by the student in the laboratory. These include many important tests and quantitative determinations, and the course, in general, seems to be a very good one. The book contains a large amount of descriptive matter, and it appears that this contains some rather serious errors. For instance, an old mistake, due to experiments with oxygen containing chlorine, is here repeated in regard to the oxygen of the air: "In materially increased amount it [oxygen] is a poison to human beings." In the chapter on metals the method for making malleable iron, the definition of steel, and the description of the smelting of sulphide ores of copper are given in a very unsatisfactory way. Malleable iron is made, not by the slow cooling of cast iron, as stated, but by the long heating of white iron castings in contact with oxide of iron; steel contains many other proportions of carbon besides the 1·5 per cent given as characteristic; it is not partly roasted copper ore that is treated in the Bessemer converter but a blast furnace product called copper matte. It is evident that students taking the course require a rather extensive preliminary chemical training, and the book is undoubtedly too technical to be recommended for the use of general readers in connection with household matters.

H. L. W.

5. *Chemical German;* by Francis C. Phillips. 8vo, pp. 252. Easton, Pa., 1915 (The Chemical Publishing Co.).—This excellent text-book, which was noticed in this Journal at the time of its first appearance, has now reached a second edition in the short period of about two years. This circumstance indicates that the book has been largely used. It has been newly printed for the new edition, but no extensive changes or additions have been made. It is again to be highly recommended as an aid to students who desire to read chemical German. H. L. W.

6. *A Compend of Medical Chemistry;* by Henry Leffmann. 12mo, pp. 241, Philadelphia, 1915 (P. Blakiston's Son & Co.

Price $1.00 net).—This little book is one of a series of "Quiz-compends" which are intended for the use of students in preparing for examinations. The volume under consideration gives a summary of inorganic and organic chemistry, including urinary analysis. As small print is used, and as the style is concise, a large amount of ground is covered. The book should be serviceable for the purpose of reviewing the subject, and it must be admitted that a student having a good knowledge of its contents should be well prepared for an examination. H. L. W.

7. *Sounds Resulting from Firing Modern Cannon and Rifles.*—The following statements are derived from a short paper by M. Agnus entitled "Le claquement de la balle et de l'obus." Since the beginning of the present European war the combatants have frequently observed a curious and unfamiliar acoustical phenomenon. It consists in an apparent repetition of the report of the gun. The French designate it as the *claquement* of the shot or shell. In general, when an observer is situated in the immediate vicinity of the trajectory of a projectile which has a velocity appreciably greater than the velocity of propagation of explosion waves in air, he hears two abrupt sounds very close together. The first aural impression is caused by the disturbance arising from the passage through the air of the rapidly moving projectile. The wave-form is somewhat similar to the resultant V-wave produced by a high-speed motor boat coursing over smooth water. The second sound is due to the arrival of the explosion wave which started from the muzzle of the fire-arm at the same instant that the projectile left the rifle. In the original paper an instructive diagram is given showing the successive positions of the first approximately hyperboloidal envelope and of the second lagging spherical explosion pulse. This figure and the following numerical data pertain to the "75 obus à balles" at different distances in front of the cannon. The time intervals corresponding to 100, 500, 1000, and 2200 meters are given as 0·1, 0·5, 0·8, and 1·2 sec., respectively. Beyond 2200 meters this projectile loses headway sufficiently, due to the resistance of the air, to cause the time intervals to decrease.

It may also be worth while to mention two other cases in which the same causes are operative. Agnus says that target recorders are acquainted with this phenomenon but are unable to explain it. They think simply that one of the sounds is due to the ball which penetrated the target or struck the ground; but they do not take into account the fact that if a ball is lost in the air without touching any solid object the two reports are perceived just the same. Again, accurate accounts of the fall of meteorites contain, without exception, the statement that a formidable detonation was heard. In general, it is said that the meteorite produces an explosion or that it bursts with a tremendous noise. If, however, the matter be looked into more carefully, it is found that the aerolite has not burst "the least bit in the world" and it is often buried in soft soil which would greatly diminish the sound of the impact with the ground. This explosion, in our opinion, can be explained very readily in the manner outlined above. It arises from the *claquement* impressed upon the air by the falling metal, and is just so much the stronger as the velocity and dimensions of the object are greater.—*Comptes Rendus*, vol. 160, No. 23, June 1915. H. S. U.

8. *Fluorescence and Resonance of Sodium Vapor.*—In attempting to extend the brilliant investigations of R. W. Wood on sodium vapor R. J. STRUTT has recently obtained the following important results :

(a) When sodium vapor is illuminated by the second line of the principal series, at λ 3303, it emits the D lines as fluorescent light.

(b) Illumination by ultra-violet light of other wave-lengths is not accompanied by emission of the D lines.

(c) If one component only of the ultra-violet doublet (3303) is stimulated, not one alone, but both of the D lines are radiated with approximately equal intensities. "This is an unexpected result, in view of the work of Wood and Dunoyer, who found that stimulation by D_2 light was unable to excite D_1 light."

(d) Excitation at λ 3303 was found to give rise neither to any observable resonance-radiation of the same wave-length, nor to any sensible emission of the lines of the subordinate series.—*Proc. Roy. Soc.*, vol. xci (A), p. 511, August 1915. H. S. U.

9. *Elementary Lessons in Electricity and Magnetism ;* by SILVANUS P. THOMPSON. Seventh edition. Pp. xv, 706, with 377 figures. New York, 1915 (The Macmillan Co.).—"For the purpose of the present edition the entire work has been completely revised, and in many parts rewritten." A careful comparison of the latest edition with the preceding text, which was reprinted in 1914, shows that the first five chapters are practically identical, the only alterations consisting in minor omissions and additions. Lesson XXXV of chapter VI marks the beginning of the rearrangement of the subject matter. Not only has the sequence of topics been changed but a great deal of new and important material has been incorporated. To enable those who have accessible a copy of the earlier edition to see at a glance the nature and extent of the revision the titles of the last eleven chapters will now be quoted. They are : "VII Electric Production of Heat ; VIII Electric Light ; IX Inductance ; X Dynamos, Alternators, and Transformers; XI Transmission and Distribution of Power ; XII Electric Traction ; XIII Electro-Chemistry ; XIV Telegraphy ; XV Electric Waves ; XVI Wireless Telegraphy" ; and "XVII Electron Theory of Electricity." The last two chapters are entirely new.

The seventh edition also possesses the following advantages over the earlier prints. The paper is better, the type larger, and the spacing of the lines wider. Whenever appropriate the text-figure is accompanied by a legend or brief description of its significance. The symbols for current, capacity, number in series, and number in parallel have been changed from C, K, m, and n, to i, C, s, and p respectively. Appendix B has been brought up to date and the appendix on the Clark cell omitted. The number of problems for solution by the student has been increased from 246 to 291. Since we have found this text very useful in our classes in the past we expect to obtain even better results with the new edition during the present winter. H. S. U.

10. *A Treatise on Light;* by R. A. HOUSTOUN. Pp. xi, 478, with 328 figures. London, 1915 (Longmans, Green and Co.).—The author says in the preface that "This book is intended for students who have been through a first year's physics course and who are proceeding further with the study of light. It differs from other books on light by a more systematic treatment, also by dealing with the full scope of the subject and including the results of recent investigations. A good knowledge of elementary mathematics is assumed. The calculus is used, but I hope that the results obtained by its aid will be intelligible to those who cannot follow the intermediate steps, and in any case the greater part of the book is free from it."

The text is conveniently divided into four Parts which deal respectively with geometrical optics (113 pages), physical optics (114 pages), spectroscopy and photometry (129 pages), and mathematical theory (100 pages). The chief topics discussed in Part I are the theory of spherical mirrors, of thin and thick lenses, and of systems of lenses, the defects of images, the determination of the constants of mirrors and lenses, optical instruments, and the determination of indices of refraction. The method of rays is used throughout. Part II deals with the velocity of light, interference, diffraction, polarization, double refraction, the propagation of light in crystals, optical rotation, and the analysis of polarized light. The third division of the text gives an account both of the historic development of spectroscopy and of all the most important results obtained by spectroscopic methods. The ultra-violet, infra-red, and Röntgen radiations are discussed at some length. The rest of Part III is devoted to photometry, spectrophotometry, the human eye, color vision, lamps, and illumination. The titles of the chapters of Part IV are: "the Nature of Light, the Electromagnetic Theory of Light, Reflection and Refraction, the Theory of Dispersion, Theory of Radiation," and "the Relative Motion of Matter and Ether." With regard to the chapter on the nature of light the author says:—"From the nature of the subject the chapter is a difficult one; it may be omitted without prejudice to those that follow."

It is thus evident that the entire field is covered with sufficient thoroughness to give the student an excellent perspective of the subject of light. The author's style is clear and concise and his presentation of the material of Part IV is especially illuminating. On the other hand, the text as a whole seems to be of a more advanced character than can usually be assimilated by a student who has had only one year of physics. At the ends of the chapters may be found "examples" (200 in all) for solution by the reader. The index is immediately preceded by a set of tables of useful optical data. The publishers have been very successful in printing the numerous mathematical formulæ clearly and accurately. The volume should be useful to teachers and graduate students as well as to undergraduates. H. S. U.

II. GEOLOGY.

1. *The Strength of the Earth's Crust;* by JOSEPH BARRELL. Jour. of Geol., vol. xxii, Nos. 1–8, vol. xxiii, Nos. 1, 5, 6, 1914 and 1915.*—The reprinting of these papers in collected form for circulation by the author puts them in very convenient shape for use by geologists, and merits calling attention to them. They constitute probably the most serious and profound discussion, which has yet been attempted, of the facts which are known and of the theories which have been deduced from them, concerning the strength of the earth's outer shell. Upon this physical feature so many conclusions drawn by geologists ultimately depend that Professor Barrell has done a valuable service in applying quantitative data from the geologic side and in discussing from the standpoint of the geologist the results obtained by physical measurements by the geodosists, and the inferences derived from them by analysis. This combination of geological and mathematical lines of attack, by one fully competent to deal with both, gives a certain authority to the conclusions drawn in the final papers. The author finds that the crust is very strong when measured by its capacity to support great deltas, mountain ranges or large internal loads due to variations in density not in accord with topography, while on the other hand the altitudes of the continents as a whole or in large sections show nearly perfect isostasy. The maintenance of such isostatic conditions through geologic time, in spite of opposing geologic activities, is held to imply the existence of a zone of undertow below the zone of compensation, which is both thick and weak to shearing stresses. Geologically such a zone, called the asthenosphere,—the shell of weakness—must have important bearings, which are treated in the later portions of the work. L. V. P.

2. *A Text-Book of Geology. Part I, Physical Geology;* by LOUIS V. PIRSSON, Professor of Physical Geology in the Sheffield Scientific School of Yale University. *Part II, Historical Geology;* by CHARLES SCHUCHERT, Professor of Paleontology in Yale University and of Historical Geology in the Sheffield Scientific School. Pp. x, 1,051, figs. 522, appendix, index, and folding colored geological map of North America. New York, 1915 (John Wiley and Sons, $4.00 net. Parts I and II sold also in separate volumes, $2.25 and $2.75 net).—This book, "dedicated

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* Copies of this memoir of about 250 pages may be purchased from the Yale Coöperative Store for 75 cents, parcel post extra.—ED.

to the memory of James Dana Dwight, explorer, geologist, naturalist, professor in Yale University," is a manual of that highest class which should be studied alike by student, teacher, and investigator. To the college student it presents a comprehensive view of the fundamental knowledge of that broad and composite science,—geology. In adaptation to his needs there will be found a clarity and simplicity of expression and avoidance of unnecessary technicalities. Numerous headings make it easy to study, since the subject matter is thus clearly indicated. The diagrams and maps possess a sharpness and definiteness which facilitate the acquisition of ideas resting on a graphic basis. The more advanced material is in a smaller type, so that it may be omitted if desired from daily assignments, but is informative and stimulating to both student and teacher.

The authors have acquired preparation for the writing of this book through many years of teaching of elementary and graduate students, and in research. As a result it not only shows a clarity and balance in the presentation of subject matter, but incorporates such recent views as have been soundly demonstrated. It gives that general survey of progress which is desirable from decade to decade for the use and reference of even the most advanced of investigators.

In the first part, the physiographic section is less voluminous than in some recent texts, giving a better balanced relation and making more room for the other portions of the subject matter. Thus 236 pages are given to Dynamical Geology and 160 pages to Structural Geology. It is the general experience of teachers that the large majority of students enter upon the study of geology with no previous knowledge of the biological sciences. For that reason, in Part II are given eight introductory chapters on such subjects as Matter and Organisms ; Evolution, the Constant Change of Living Things ; Fossils, the Geologist's Time Markers, etc. The work is made more human by the addition of portraits of the founders of geology and a larger treatment in the form of a special chapter on the geologic evidence of "Man's Place in Nature." The concluding chapter is a summation entitled "Earth History in Retrospect."

The quality of the paper, printing, and binding are excellent, and the many illustrations, largely new, not only give clearness, but add attractiveness to the work. J. B.

3. *Grundlagen der physicalisch-chemischen Petrographie ;* von H. E. Boeke, Ph.D. Pp. 428, 8vo; figs. 167, tables 2. Berlin, 1915 (Gebr. Borntraeger).—In this volume the author, who is professor of mineralogy and petrography in the recently established university at Frankfort-on-the-Main, has presented a work, which for study and reference in certain fields of petrology will undoubtedly prove very useful. A certain amount of physical chemistry, applicable to petrogenetic problems, has been advantageously introduced into their works on igneous rocks by Harker and Iddings, and some of the phases of the subject are covered in

Wulffs' treatise on volcanism. But a systematic gathering and presentation in well-digested form of the great mass of material which in recent years has accumulated in the domain of physical chemistry and has a bearing on petrogenesis, is much to be desired. In this country the work of Day and his co-laborers in the Carnegie Geophysical Laboratory is well known; that of other investigators in other places, less directly connected with geological problems, is often quite unknown to petrologists. Moreover, the relative value of much of the material, and its bearing on the problems of petrology, are not directly evident. Yet it is certain, as the author remarks, that it is along this inductive path of experimental synthetic investigation that the greatest progress in the science, in its present stage of development, is to be made. From what has been said the general nature of the work is evident, but the following details will give an idea of its plan and scope. After an introductory statement respecting homogeneous and heterogeneous equilibrium, the author takes up the general subject of magmatic petrogenesis, which comprises about one-half of the volume. Under this heading he discusses a variety of topics, such as the melting point of minerals under varied conditions; the properties of siliceous melts, such as viscosity, surface tension, electrical conductivity, density, etc.; enantiotropism and monotropism, the thermal properties of minerals, etc.; and then treats first of two component systems, under which eutectics, isomorphism, and solid solution are comprised; and afterwards of systems of three, four and more components. Finally a review of the chemico-physical, and especially the thermal properties of the main rock-making minerals, individually considered, closes this portion of the work.

In the second part the volatile constituents of magmas are treated; their properties, solubility in molten solutions, the equilibrium of gases, etc., etc.

The author then, in the third part of the work, discusses the pegmatitic, pyroaqueous and hydrothermal phases of magma solidification. Here such subjects as the properties of water at high temperatures, critical temperatures and pressures, the formation of minerals in systems with volatile components, and a variety of other matters which have important bearings on the formations of certain rocks and ore-deposits, are treated.

Next comes the subject of weathering, then of sediments, under which latter the problems of dolomite and salt deposits are considered, and the work concludes with a section on metamorphism.

This sketch will give the reader a notion of the ground covered. While such a work is necessarily one of compilation, and the writer has selected his material well and expressed it concisely in clear language, it is noticeably impersonal in tone, and editorial comment and criticism are on the whole rare. Where such occurs they are quite conservative in character. It is rather in the selection of the material that the author passes judgment. The work has, therefore, a rather synoptic and somewhat statistical character, which especially fits it for ready reference. It is to be hoped that it will find general use among those interested in the genesis of rocks, minerals, and ores. L. V. P.

4. *Papers from the Geological Department of Glasgow University ;* Vol. i, 1914.—This volume contains a collection of some 19 papers, previously published in a variety of journals, proceedings, etc., by Professor J. W. Gregory and other members of the geological department of the University, together with the text of an address delivered by the former, upon the work of Livingstone as an explorer, at the Livingstone Centenary in March, 1913. The collection contains a number of valuable and suggestive papers and is good evidence of the activity which prevails in this field of science in Glasgow under the energetic leadership of the senior author. L. V. P.

III. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *National Academy of Sciences.*—The autumn meeting of the National Academy was held in New York City on November 15, 16, 17. The sessions were conducted in the American Museum of Natural History, Dr. Charles D. Walcott presiding in the absence of the president, Dr. Welch. The scientific work of the meeting was opened by a lecture by Professor M. I. Pupin on "The Problem of Aerial Transmission," delivered on Monday evening ; the titles of the papers presented for reading on Tuesday and Wednesday are given below. The members of the Academy, a large number of whom were in attendance, were entertained by the President and Trustees of the Museum on Monday evening ; at a dinner at the Chemists Club on Tuesday evening, given by the New York member of the Academy, and on Wednesday noon and afternoon at the Zoological Park and the Botanical Garden in the Bronx.

The titles of the papers are as follows :

E. G. CONKLIN : Nature of cell polarity.

W. E. CASTLE : Is selection or mutation the more important agency in evolution ?

A. E. VERRILL : Inheritance of clubbed feet through five known generations. Inheritance of abnormal or defective thumbs through four known generations.

C. B. DAVENPORT : Heredity of stature.

E. C. MACDOWELL : Parental alcoholism and mental ability—a comparative study of habit formation.

J. B. MURPHY : Rôle of the Lymphocytes in resistance to cancer.

GRAHAM LUSK : The calorimeter as an interpreter of life processes.

T. B. OSBORNE and L. B. MENDEL : The resumption of growth after failure to grow.

W. H. HOWELL : Ultramicroscopic studies of the fibrin-gel.

C. WILLIAM BEEBE : Origin of the flight of birds.

FRANK M. CHAPMAN : Ornithological survey of the Andes and Western Coast of South America.

DOUGLAS H. CAMPBELL : Treubia.

M. A. Howe: Fossil calcareous Algæ from the Panama Canal Zone with reference to reef-building Algæ.
A. B. Stout; Sterility in plants and its inheritance.
J. N. Rose: Recent explorations in the cactus deserts of South America.
G. H. Shull: Some factors affecting the inheritance ratios in Shepherd's Purse.
H. M. Richards: The respiratory ratio of cacti in relation to their acidity.
R. A. Harper: Some studies in morphogenesis.
H. S. Jennings: Can we observe organic evolution in progress?
J. M. Coulter: Orthogenesis in plants.
T. W. Richards: Investigations recently conducted in the Wolcott Gibbs Memorial Laboratory.
B. B. Boltwood: The life of Radium.
G. C. Abbot: The solar radiation and its variability.
A. G. Webster: Experiments and theory of conical horns. Instruments for measurements of sound. An instrument for finding the direction of a fog-signal.
E. C. Pickering: The new Draper Catalogue.
H. N. Russell: On the Albedo of the Moon and Planets.
G. F. Becker: A possible origin for some spiral nebulæ.
L. A. Bauer: Concomitant changes in the Earth's magnetism and solar radiation.
Fred E. Wright and J. C. Hostetter: Experiments on the mean free path of gases. Observations on Wood's one-dimensional gas.
James Kendall: The water correction in conductivity determinations.
H. F. Osborn: Extremes of adaptation in the carnivorous dinosaurs, Tyrannosaurus and Ornithomimus.
C. K. Leith: The influence of certain minerals on the development of schists and gneisses.
W. M. Davis: Glacial sculpture of the Mission Range, Montana.
Waldemar Lindgren: Crystallization of quartz veins.
G. P. Merrill: The minor constituents of meteorites.
E. W. Hilgard: A peculiar clay from near the City of Mexico.
A. G. Mayer and R. S. Woodward: The biography of Alfred Marshall Mayer.

2. *Memoirs of the National Academy of Sciences.* Volume XII, Part II, Second Memoir. Quarto, pp. 94, with 61 plates. Washington, 1915.—This volume is devoted to an exhaustive and fully illustrated discussion by Chas. C. Adams of "The variations and ecological distribution of the snails of the genus Io."

3. *The Craniometry of the Southern New England Indians;* by Vera Marian Knight, A.M., with an introduction by Harris Hawthorne Wilder, Ph.D., Smith College Anthropological Laboratory. Memoirs of the Connecticut Academy of Arts and Sciences, vol. IV, pp. 36, 10 pls., 2 tables. New Haven, 1915.—There is a lamentable dearth of published data concerning the osteology of the American Indians. Skeletal remains of the aborigines stored in many museums are, for the most part, unstudied. Very few reports of American archeological investigations have included adequate accounts of the osteological material found. Practically the only studies of long series of American crania available for comparative purposes were made when anthropology was in its infancy in this country and are now more or less out of date.

Miss Knight's contribution to the craniometry of the New England Indians is, therefore, very welcome. The author has omitted to state the number of specimens studied, but, as far as can be made out from the tables, the paper consists of measurements on 93 different crania. Wherever possible, 57 measurements have been taken on each skull. The reviewer has had an opportunity to observe the careful way in which the work has been done. The measurements have been used for the calculation of indices and on the basis of the latter frequency curves have been plotted. Metric studies such as this, produced by a careful student who has had competent instruction and ample practice in craniometry, and who has a knowledge of the statistical methods used in biology, are greatly needed. Yet Miss Knight's paper is the only one of its kind that has appeared lately in this country.

Two suggestions may be made in regard to the handling of the data contained in this paper. The standard deviation and probable error should have been computed. In the investigation of such a group comparable material should be drawn, if possible, from neighboring groups. For example, we are not interested in a comparison of the length-breadth indices of the New England Indians with those of the Czechs. One of course realizes that the author exhibits Bohemians and Kamerun Negroes only because of a scarcity of comparable American data. Yet there was no necessity of going so far afield. It is to be regretted that there is included in this paper no descriptive matter whatsoever. It is now generally recognized that it is impossible to establish a physical type by mere measurements. Morphological observations are absolutely essential. The investigation is called "an attempt to determine as accurately and completely as possible, by the anthropological methods in use at present, the racial cranial characteristics of the Southern New England Indians." This task cannot be accomplished by the mere manipulation of calipers. Average measurements do not constitute "racial cranial characteristics."

Nevertheless physical anthropologists in this country are much indebted to Miss Knight for this useful study, and it is to be hoped that she will continue her work along this line.

E. A. HOOTON.

Peabody Museum, Harvard University.

4. *Publications of the British Museum of Natural History.*—The following volumes have been recently issued (see vol. xl, p. 96):

Catalogue of the Books, Manuscripts, Maps and Drawings in the British Museum. Vol. V. SO—Z. Pp. 1957–2403, 4to, London, 1915.—This fifth volume of the catalogue of books, maps, etc., in the natural history branch of the British Museum, completes the entries of author's names; it has been in the press since June, 1913.

Catalogue of the Ungulate Mammals in the British Museum; by R. Lyddeker, F.R.S. Vol. IV, pp. xxi, 438; 56 text-figures. —The families included in this volume are the Deer, Chevrotains, Camels and Llamas, Pigs and Peccaries and the Hippopotamuses, thus completing the Artiodactyla. A fifth and final volume, embracing the Perissodactyla, the Hydracoidea and the Proboscidea has been planned, but it is uncertain when this can be accomplished. Unfortunately, the gifted author, Dr. Lyddeker, was stricken by illness when the fourth volume, now noticed, was nearly completed. He was able to finish the revision of the proofs, but finally died on April 16.

The Louse and its relation to Disease ; by BRUCE F. CUMMINGS. Pp. 16 ; 4 figs.—This pamphlet presents a subject which has recently come into prominence by the conditions brought about by the war. The life history of the louse, its habits, and the method of combating it are the topics particularly discussed.

5. *Contributions from the Princeton Observatory*, No. 3. *A Study of the Orbits of Eclipsing Binaries ;* by HARLOW SHAPLEY. Pp. xiv, 176. Princeton, 1915 (published by the Observatory).—The method of computing the orbit of eclipsing binaries from data furnished by the light-curve obtained from photometric measures of the light of the star is the most recent striking development in astronomy. When the work recorded in this volume from the Princeton Observatory was begun, in October 1911, there were scarcely 10 eclipsing binaries whose orbits had been even approximately determined by any method. Now the number is a round 100, which is equal to the number of computed orbits of visual doubles ; 90 of these orbits, all determined with much accuracy, are recorded in this volume, which was completed early in 1914.

The author has made these orbits the basis of much valuable investigation, such as that on the polar compression of the stars in various of these pairs, the types of spectra represented among them, and the distribution of eclipsing binaries in space. The whole volume is an admirable example of thorough-going, consistent, reliable scientific work, and practically exhausts the subject. W. B.

6. *Publications of the Cincinnati Observatory ;* JERMAIN G. PORTER, Director. No. 18. Part I. Catalogue of Proper Motion Stars. Pp. 70. Cincinnati, 1815.—In this new catalogue of proper motion stars, it is proposed to include all those stars having a motion of ten seconds a century or greater, excluding, however, the fundamental stars of the Berlin Jahrbuch and the American Ephemeris, and further those contained in the recent Boss Preliminary Catalogue.

7. *Nature and Science on the Pacific Coast.*—Pp. xii, 302; 19 text figs., 21 pls., 14 maps. San Francisco, 1915 (Paul Elder & Co.).—This is a guide-book for scientific travelers in the west, prepared under the auspices of the Pacific Coast Committee of the American Association. Although planned to fill a local need, it has also a permanent value. The chapters, upward of thirty in number, are written by men of well-known reputation and cover every part of the field; they are admirably illustrated.

8. *The Mining World Index of Current Literature.* Vol. vii, first half year, 1915; by GEORGE E. SISLEY. Pp. ix, 208. Chicago, 1915 (Mining World Company).—A seventh volume has been added to the series of indexes, issued by the editor of the Mining and Engineering World, embracing the world's literature in mining, metallurgy and kindred subjects for the period, January to June, 1915.

9. *Les Prix Nobel en 1913.* Stockholm, 1914 (P. A. Norstedt & Söner).—This volume gives an account of the distribution of the Nobel prizes in 1912. The recipients of the prizes were: in physics, Heike K. Onnes; in chemistry, Alfred Werner; in physiology and medicine, Charles Richet; in literature, Rabindranath Tagore. Portraits and biographical notices of these gentlemen are given and also the addresses delivered by several of them at the Nobel conferences on December 11.

It may be added that, according to a recent press statement, the Nobel prizes for 1915 are to be awarded as follows: in chemistry, to Dr. R. Willistätter of Berlin; in physics, to W. H. Bragg and W. L. Bragg of Cambridge, England, for their researches on the structure of crystals by means of Röntgen rays.

10. *The Leeward Islands of the Hawaiian Group;* by CARL ELSCHNER. Pp. 68, 8vo, 1915.—This pamphlet contains in privately printed form a number of contributions to the Honolulu Sunday Advertiser. It consists of observations of various kinds and values on the islets, reefs, etc., stretching westward from Hawaii. These observations relate to the geography, geology, fauna, flora, and especially to the chemical character of the changes going on in the reefs through influences of life and the resultant deposits, the latter being chiefly phosphatic. The author, who is a chemist and expert in phosphates, gives a considerable amount of interesting data respecting these diagenetic processes.
L. V. P.

OBITUARY.

DR. RAPHAEL MELDOLA, the distinguished English organic chemist, died on November 16 at the age of sixty-six years.

PROFESSOR EDWARD ALFRED MINCHIN, the English zoologist, died at Selsey on September 30 at the age of fifty-nine years.

DR. THEODOR ALBRECHT, of the Royal Prussian Geodetic Institute, Potsdam, died on August 31 at the age of seventy-two years.

WIRT TASSIN, from 1893 to 1909 chief chemist and assistant curator of mineralogy in the U. S. National Museum, died on November 2 in his forty-seventh year.

INDEX TO VOLUME XL.*

*This Index contains the general heads, CHEMISTRY, GEOLOGY, MINERALS, OBITUARY, ROCKS, ZOOLOGY; under each the titles of Articles referring thereto are included.

TEN-VOLUME INDEX. 1911-1915.

The *Index* to volumes XXXI-XL, to be ready for distribution about January 1, 1916, completes the present volume. It will be sent only when specially ordered. Price ONE DOLLAR.

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