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Irregular Publications

In the interest of exact bibliography, the Society takes cognizance of all publications issued either wholly or in part under its auspices. Each author of a memoir receives 30 copies without cost, and is authorized to order any additional number at a slight advance on cost of paper and presswork; and these separate brochures are identical with those of the editions issued and distributed by the Society. Contributors to the proceedings are also authorized to order any number of separate copies of their papers at a slight advance on cost of paper and presswork; but such separates are bibliographically distinct from the brochures issued by the Society.

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† Fractional pages are sometimes included.

CORRECTIONS AND INSERTIONS

All contributors to volume 7 have been invited to send in corrections and insertions to be made in their compositions, and the volume has been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention:

Page 2, line 15 from top; *for* "Taft" *read* "Taff"
" 104, " 1 " " ; *for* "microline" *read* "microcline"
" 152, " 14 " " ; transfer "when" to line above after "pressure"
" 168, under *Melonites multiporus*, number 2290, column 7, *transpose* "........" and "Truncates initial plate 3."
" 212, line 22 from top; *for* "their regular" *read* "the irregular"
" 236, " 2 " " ; *for* "order" *read* "subclass"
" 249, " 13 " " ; *for* "I" *read* "J"
" 256, footnote; *for* "Journal" *read* "Journey"
" 261, " ; *for* "Beiträge" *read* "Beyträge"
" 270, line 3 from top; *for* "above" *read* "about"
" 274, footnote; *for* "Descripçõo" *read* "Descripção"
" 277, " ; *for* "Capenena" *read* "Capenema"
" 278, " ; *for* "§§ Beiträge" *read* "§§ Beyträge"
" 320, line 16 from top; *for* "Herbert" *read* "Hebart."
" 356, footnote; *for* "14.93" *read* "13.466"
" 359, lines 20 and 22 from top; *for* "Chamberlain" *read* "Chamberlin"
" 532, line 17 from top; *insert* Moritz Fischer, Field Columbian Museum, Chicago, Ill. May, 1889.
" 538, line 2 from top; *for* "228" *read* "229."
" 538, " 3 " " ; *for* "141" *read* "142."

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 7, PP. 1-16 NOVEMBER 11, 1895

PROCEEDINGS OF THE SEVENTH SUMMER MEETING, HELD AT SPRINGFIELD, MASSACHUSETTS, AUGUST 27 AND 28, 1895

HERMAN LE ROY FAIRCHILD, *Secretary*

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SESSION OF TUESDAY, AUGUST 27

The Society convened at 10 o'clock a. m. in the lecture-room in the Art Museum of the City Library Association, the President, Professor N. S. Shaler, in the chair. After calling the meeting to order the President introduced the Librarian of the City Library Association, Reverend William Rice, D. D., who made a brief address of welcome. The President responded to this address, and then announced the death of two Fellows, James D. Dana and Henry R. Nason.

ELECTION OF FELLOWS

The Secretary announced the result of the balloting for Fellows, as canvassed by the Council, as follows:

Fellows Elected

SAMUEL PRENTISS BALDWIN, A. B., Cleveland, Ohio. Lawyer.
OLIVER CUMMINGS FARRINGTON, B. S., Ph. D., Chicago, Illinois. In charge of Department of Geology, Field Columbian Museum.

George Perry Grimsley, B. A., M. A., Ph. D., Columbus, Ohio. Professor of Geology in Washburn College, Topeka, Kansas.

Frederick Putnam Gulliver, A. B., A. M., Norwich, Connecticut. Now engaged in research work in Physical Geography.

John Bell Hatcher, Ph. B., Princeton, New Jersey. Assistant in Geology and Curator of Vertebrate Paleontology, Princeton College.

Edward Bennett Mathews, A. B., Ph. D., Baltimore, Maryland. Instructor in Petrography and Mineralogy, Johns Hopkins University.

John Campbell Merriam, B. S., Ph. D., Berkeley, California. Instructor in Paleontology in the University of California.

Henry Benjamin Charles Nitze, B. Sc., E. M., Baltimore, Maryland. Engaged in Economic Geology upon the North Carolina Geological Survey.

Frederick Leslie Ransome, B. S., Berkeley, California. Fellow in Mineralogy in the University of California.

Joseph A. Taft, B. S., Washington, District of Columbia. Assistant Geologist, U. S. Geological Survey.

Charles Schuchert, Washington, District of Columbia. Assistant Curator, Department of Paleontology, U. S. National Museum.

The report of the committee on the Royal Society catalogue of scientific papers, which was laid upon the table at the Baltimore winter meeting for printing,* was taken from the table for final action and adopted without debate.

A report from the special committee on the Mount Rainier Forest Reserve was read by the Secretary. This report described the efforts of the committee to secure favorable action by the late Congress, their labors thus far being unsuccessful. The report was accepted as a report of progress, and the committee was continued, with the addition of the President to its membership. The committee now consists of S. F. Emmons, Bailey Willis and N. S. Shaler.

It was voted to adopt the rule regarding the order of papers in reading which had been in force the three previous meetings.

The reading of papers was declared in order, and the first paper read was as follows:

CHAMPLAIN GLACIAL EPOCH

BY C. H. HITCHCOCK

[*Abstract*]

Accepting the view of James Geikie of the divisibility of the Ice age into a series of temperate and glacial epochs, one desires to determine the positions of the several deposits in North America, especially on the Laurentian area. It seems probable that the Scanian Pliocene epoch of Geikie may be matched by the Lafayette;

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* See this publication, vol. 6, p. 457.

the Saxonian epoch of Geikie may be correlated with the Kansan stage of Chamberlin, and so the European Polandian may have been the equivalent of the Iowa stage. Authors have also correlated the Mecklenburg of Geikie with the Wisconsin of Chamberlin. So far there seems to be agreement, but the remaining epochs are paralleled with great difficulty. I desire to call attention to the Champlain deposits and ask whether they were not laid down during a period of cold. I will specify a few of their features:

1. The term Champlain was first applied by me in 1861 to the fossiliferous clays of the Champlain and Saint Lawrence valleys. It included two marine sets of strata, the lowest carrying shells like *Leda* at considerable depths; the upper characterized by littoral mollusca, like *Saxicava*, and certain delta deposits.

2. The species are such as now live in Arctic regions, as Labrador, none of them coming south of the north part of the gulf of Saint Lawrence. Dawson describes 207 species, and my Portland, Maine, catalogue gives 121 species, almost entirely included in the Canadian list. On the Atlantic coast this Labrador fauna has been recognized as far south as Gloucester, Massachusetts, but the influence of what was probably the same climate extended to Nantucket, where the upper Sankaty Head beds contained shells whose summer temperature must have been from 55° to 60° Fahrenheit, fifteen degrees colder than the warmer season of the creatures living in the lower Sankaty Head beds.

3. The land near New York seems to have been depressed at this time from 50 to 75 feet; in northern Vermont the depression amounted to 400 feet, and to 600 feet at Montreal. The deformation amounted to about one and one-fourth feet to the mile.

4. With such a change of level south-flowing streams would have their sources depressed very much more than their mouths, and hence they would contribute extensive deposits of fluviatile clay, such as are recognized in the middle terraces. Some of these beds carry leaves of Arctic plants, indicating a colder climate than now prevails, and at Hoboken they hold fresh-water diatoms nearly at the sea-level.

5. Seventy-nine species of maritime plants bordering the great lakes as far as Minnesota, marine shrimps and insects upon lake Superior, and such fish as *Triglopsis thompsoni* in lake Michigan required the presence of ocean water to bring them to their present habitats, so that a submergence of the interior of the continent for 700 or 800 feet is called for, and probably the time was that of the deposition of the Champlain clays.

6. The development of the fluviatile clays often blocked up the courses of the rivers, so that the renewed stream was compelled to change its course and fall over ledges, and this phase of action belonged to the Champlain epoch. Illustrations of this change of bed are to be found on the Merrimack river at Lawrence and Lowell, Massachusetts, and Manchester, New Hampshire; on the Connecticut at Holyoke, Turners Falls, Massachusetts, and Bellows Falls, New Hampshire.

7. With a submergence of probably of from 1,000 to 1,500 feet in the lower Saint Lawrence and an Arctic climate, glaciers would form on three or four mountainous regions, as the Laurentides, Green and White mountains and the Adirondacks, and would discharge bergs in an inter-island area, involving the attendant dispersion of boulders. There would likewise have been a southwest current from the Arctic regions between Labrador and Newfoundland, which carried cooling influences over the whole of the Champlain area and originated till and southwest striæ.

8. More particularly the signs of local glaciers have been pointed out by my father and myself for the Green mountains in Massachusetts and Vermont; by L. Agassiz and myself for the White mountains; by myself for the whole northwest border of Maine, and by Ells and Chalmers for Quebec. The latter authors, with Dawson, are disposed to believe that there were no other than local glaciers in the whole northern slope of the Atlantic district; but we have evidence of older ice-sheets from a lower till in the Chaudiere valley, from the same at Bethlehem, New Hampshire (Agassiz), and from the peculiar dispersion of boulders down the Ammonoosuc valley from the west flanks of the White mountains. There can be no question of the presence of local glaciers in northern New England, passing over sheets of underlying till that were laid down by a mightier glacier; but it is a matter of inference that these were coeval with the Champlain depression.

9. The drumlins of eastern Massachusetts were probably formed at this same Champlain epoch, for they contain not less than 55 species of mollusca (Crosby), in fragmental condition, which lived in an earlier temperate climate. They are not Pliocene, and hence belong to the Pleistocene. They have been transported by ice from Massachusetts bay upward into the drumlins some 300 or 400 feet. The glacier or possibly floating ice that transported these shells must have belonged to a late date, and may for the present be correlated with the Champlain.

10. It is possible to harmonize the glacier and iceberg theories by accepting the above mentioned facts. The Lyellians demand nothing more than is conceded by the adoption of the Champlain epoch as one of the glacial stages. Those who adopt the diversity theory of ice ages are willing to give the Lyellians one epoch when they can find everything else to correspond with their views. If these extremes can thus join hands over this icy chasm there need be no more animated discussion over fundamental principles.

11. The Champlain epoch, as now defined, corresponds very well with the Mecklenburg stage of Geikie, for both had the characteristic marine molluscan fauna, the Arctic flora (*Yoldia* beds of the Baltic), and best illustrate the isobases of De Geer. The abundant moraines of the Baltic area may find an analogue in the drumlins of the east, and perhaps the Wisconsin moraine may also be correlated with the Champlain.

The paper by Professor Hitchcock was discussed at length, the following Fellows participating: I. C. White, J. F. Kemp, J. W. Spencer, W. M. Davis, H. S. Williams and N. S. Shaler.

The second paper was—

GLACIAL GENESEE LAKES

BY HERMAN L. FAIRCHILD

The paper was discussed by I. C. White, J. W. Spencer, N. S. Shaler, H. S. Williams and W. M. Davis.

Following the discussion of the above paper the Society adjourned for the noon recess.

Upon reassembling at 2.15 o'clock p. m. the following paper, descriptive of the geology of the locality, was read:

GEOLOGY OF OLD HAMPSHIRE COUNTY, IN MASSACHUSETTS

BY B. K. EMERSON

[*Abstract*]

Contents

THE AREA DISCUSSED

Old Hampshire county includes Franklin, Hampshire and Hampden counties, and Springfield is in the center of the latter.

THE CRYSTALLINE ROCKS

On the western border of the Green Mountain area as it crosses Massachusetts and overlooking the Housatonic valley is a series of pre-Cambrian outcrops, which are the oldest rocks of the state and the substratum on which the others rest. They consist of coarse gneisses, especially characterized by blue quartz and allanite, coarse porphyritic structure and stretching, and by great beds of highly crystalline limestone, with chondrodite, coccolite, titanite, phlogopite and wernerite.

The most important of these beds are the Hoosac, the Hinsdale and the Tyringham areas, and the limestone beds connected with the two latter have caused the two most important passes through the range—the Westfield and the East Lee-Farmington valley.

On the pre-Cambrian rocks rest the Becket conglomerate gneisses of Cambrian age, and above them a great series of sericite schists (the Hoosac schists, Rowe schists, Chester amphibolite and Hawley schists), which are about cotemporaneous with the Stockbridge limestone of the Housatonic valley.

The Chester amphibolite series, containing many serpentine beds and the celebrated Chester magnetite-emery bed, divides this series into two members, and the highly ferruginous Hawley schists cap the series in the northern part of the state.

A considerable unconformity separates the next series—the calciferous mica-schists of Hitchcock (the Goshen and Conway schists)—from the sericite-schists. These are dark biotite-spangled garnet-schists, which are probably Upper Silurian. They are greatly cut by large granite masses and graduate upward into the Leyden argillites. Upon these rest unconformably the Upper Devonian Bernardston series of highly crystalline amphibolites, mica-schists and fossiliferous quartzites and limestones.

Crossing from the Housatonic to the Connecticut, one passes from a region of rocks which have been folded under a heavy load without faulting to an area which has been deformed under an inadequate load, and which is faulted into great blocks and greatly cut by granites.

The Trias

The Trias occupies the broad valley of the Connecticut, beginning in Westfield, near the state line, as a narrow remnant and widening as it crosses the Connecticut line to above 20 miles.

It consists of (1) very coarse conglomerate along its eastern border—the mount Toby conglomerate; (2) of a coarse arkose or feldspathic sandstone and conglomerate on the western border—the Sugarloaf arkose; (3) of a rusty sandstone—the Longmeadow brownstone—in its more central parts; (4) while down the central line of the valley a series of shales and calcareous beds marks the deepest portion of the ancient bay. The deposition of these coarse sediments was interrupted by the outflow of the great Deerfield and Holyoke trap-sheets, which were submarine and which, filling up the deeper portion of the channel, have been covered by fine calcareous mud. This mud has been intimately mingled with the scoracious upper surface of the trap for 12 miles, and also underrolled, so that similar masses form the base of the bed.

After the deposition of sand had deeply covered the great trap-beds mentioned above, another bed flowed out over the sea bottom, and immediately following this came an explosive eruption at a point south of mount Holyoke, which spread tuff over a broad area of sea bottom. This was followed by a long series of isolated outbursts of trap along the old fissure by which the great flows had come up earlier, which may have formed volcanoes on the surface, but which appear now as cores cutting across all the other rocks.

The character of the basin in which the beds were deposited, the succession of the same and the subsequent monoclinal faulting and erosion were illustrated by detailed maps and models.

The Quaternary Deposits

A detailed map of the surface geology was exhibited, the drumlins and other forms of till being shown in detail, and attention was especially called to the mapping of the glacial lake and stream beds.

The area is divided into three topographic parts—the eastern and western plateaus and the central valley of the Connecticut river. This valley runs north and south, while the ice retreated north 35° west, with a lobe extending down the central valley. This enabled the ice to free the eastern side valleys in their headwaters first, causing a series of lakes, which drained off east of the Connecticut river. This was followed by the series of Connecticut lakes—the Montague, the Hadley and the Springfield lakes—occupying the broad valley bottom, and, finally, a series of stream beds was formed by the retreat of the ice across the western plateau and up the preëxistent valleys from their mouths to their sources.

Attention was called to the distinction of filled and unfilled lakes, and to the repulsion of tributaries across construction terraces. It was shown that the tributaries run for long distances parallel to the main stream, because the terrace is made up of many confluent islands, around the lower ends of which the tributary successively finds its way.

Attention was also directed to the great preponderance of ox-bows and bends on the right-hand side of the Connecticut and its tributaries, where they cross the fine sands and clays of the Champlain epoch—an effect to be referred to the rotation of the earth.

Remarks were made upon the paper by W. M. Davis, C. H. Hitchcock and C. R. Van Hise.

The next paper was—

EOCENE FAUNA OF THE MIDDLE ATLANTIC SLOPE

BY WILLIAM B. CLARK

The following two papers were read by the senior author as a single paper:

STUDIES OF MELONITES MULTIPORA

BY R. T. JACKSON AND T. A. JAGGAR

STUDIES OF PALECHINOIDA

BY R. T. JACKSON

The papers were discussed by A. Hyatt and N. S. Shaler. They are printed in full in this volume.

The following paper was read:

PRE-CAMBRIAN VOLCANOES IN SOUTHERN WISCONSIN

BY WILLIAM H. HOBBS

Remarks were made by C. R. Van Hise and Florence Bascom.

The next paper was—

GEOLOGICAL SKETCH OF THE SIERRA TLAYACAC, IN THE STATE OF MORELOS, MEXICO

BY A. CAPEN GILL

Remarks were made by W. M. Davis, B. K. Emerson, N. S. Shaler and J. W. Spencer.

The Society adjourned. No evening session was held.

Session of Wednesday, August 28

The Society was called to order at 9 o'clock a. m., the President in the chair.

The first paper read was—

BEARING OF PHYSIOGRAPHY ON UNIFORMITARIANISM

BY W. M. DAVIS

[*Abstract*]

It is desirable to open this brief paper with a definition of physiography and geography, the latter being the study of the earth in relation to man, the former being such study of the earth as is necessary in order to understand its relations to man. One of the important divisions of physiography concerns itself with the study of the lands; and in order to appreciate the existing facts of land form, their development is carefully considered. This division of the subject covers geomorphology and geomorphogeny of some authors, the genetic considerations being included under physiography, not for their own sake, but for the light that they throw on land morphology. For example, in attempting to understand the geographical conditions of Pennsylvania, including therein the distribution of population, products and industries in their relation to the features of land form, it is essential that both classes of facts should be accurately known; and it is the duty of physiography to supply a fitting account of the second class of facts.

An absolute, empirical description of the land forms is unsatisfactory; it is arbitrary in arrangement, unsympathetic with the real life of the forms concerned and generally very unsuccessful in its effort to see the facts that are to be described. For these reasons a description based upon natural genetic conditions is to be preferred; it is rational in arrangement, thoroughly sympathetic with the real life of the land and most aidful in bringing to sight and mind the characteristic elements of form; it enlivens physiography much in the same way that the principle of evolution has enlivened botany and zoölogy. It thus becomes the duty of the physiographer to acquaint himself with the development of land features, not merely that he should understand the process and sequence of development, but chiefly so that he shall better perceive the products of development. The land chapter of physiography might therefore be defined as the study of the earth in relation to its surface forms, including the arrangement and character of the elements of form. Knowing that existing forms are dependent on antecedent conditions, physiography might be defined, following Mackinder, as the "study of the present in the light of the past." The results of this study furnish us a knowledge of the earth with which we enter geography.

Geology is the study of the earth in relation to time. The guiding principle in this study is that present processes are the best guides to the understanding of past processes, this being the teaching of Hutton and the British school in general. Geology may therefore be defined, again following Mackinder, as the "study of the past in the light of the present." Uniformitarianism, reasonably understood, is not a rigid limitation of past processes to the rates of present processes, but a rational association of observed effects with competent causes. Events may have progressed both faster and slower in the past than during the brief interval which we call the present, but the past and present events differ in degree and not in kind. This rather elastic understanding of uniformitarianism seems to me comparatively safe from the objections that have been urged against the more rigid conception that some authors regard as necessarily intended in the writings of

Hutton, Playfair and Lyell, especially safe if the very remote hypothetical past of unrecorded time is not considered.

Now, the conditions and processes postulated in the physiographic study of land forms are among the cardinal principles of uniformitarianism. The success in the interpretation of nature by arguments based on these postulates confirms their correctness, and thus brings to the support of uniformitarianism a large class of facts, whose bearing on these principles was not at all perceived when they were announced by their early advocates; indeed, at that time and for a long interval afterward the facts here referred to were not known. The facts are those concerning the form and arrangement of rivers and river valleys, as dependent on the denudation of the lands.

In older geological and geographical writings, valleys have been explained as fractures in the earth's crust or as the channels formed by ocean currents during a time of submergence. The modern explanation, so apparent and so acceptable to us now, that most valleys are the result of the wasting of the land under the guidance of the local stream or river, slowly gained acceptance through the middle of this century; but the wide application of this explanation—that land areas may be practically baseleveled by the wasting of slopes until the hills disappear and the valley floors become essentially confluent—is still overlooked by many geologists. Singularly enough, the British school of geologists is especially slow in making this application of the principles of uniformitarianism; even when furthest inland the British geologist is still so little removed from the ocean shore that he prefers to look on evenly denuded areas as surfaces of marine planation and not as subaërial peneplains.

In discussing the origin and arrangement of valleys as the result of every-day processes there are two important groups of considerations to be borne in mind: First, the incision of valleys along lines where the streams took their positions when the land mass under investigation assumed essentially its present attitude with respect to baselevel: antecedent, consequent and revived streams would come under this heading; second, the spontaneous development of new streams and rearrangement of old streams, resulting from the reaction of the streams on the structures: subsequent and obsequent streams,* as well as all questions of migration of divides and diversion of streams, would come under this heading.

Those geologists who some fifty or sixty years ago turned attention to the production of valleys by the work of the streams that occupy them considered only the first of these groups of considerations, and that incompletely. They did not give particular attention to the manner in which streams were located at the beginning of their erosive work, and they did not carry the process of valley-widening to its legitimate conclusion. They were chiefly occupied with the production of young, adolescent and mature valleys. The result of their teaching is seen in the selection of narrow valleys to illustrate the success of streams as valley-makers: the stream cutting down its own channel and carrying away the waste that falls into it from the side slopes. But if success is measured by the magnitude of work accomplished, wide-open valleys or, still better, peneplains of subaërial denudation, and not gorges and canyons, should be cited in illustration of what streams can do in the way of valley-making. This, however, is seldom the custom even today. The deep and narrow valley is truly more immediately impressive than the peneplain.

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* For definition of terms see (London) Geographical Journal, February, 1895, p. 134.

The canyon of the Deerfield in western Massachusetts or of the Kanawha river in West Virginia is a more manifest illustration of the principles of uniformitarianism than the uplifted peneplain in which it is incised; but when the meaning of the peneplain is fully realized it will come to be regarded as a much more important witness than the gorge to the long continued action of every-day processes. The gorge may well be subpœnaed first, but the case will not be fully proved until the wide valley and the peneplain are called in to give their remarkable confirmatory testimony.

It is only within about twenty years that the second group of considerations has been seriously discussed. Earlier writings show few, if any, traces of them. For example, in Major Powell's explanation of the canyon of Green river through the Uinta mountains, antecedent and subsequent rivers are considered, but no mention is made of the possible occurrence of subsequent rivers self developed by headwater erosion along the strike of weak strata. Hence the argument for the antecedent origin of Green river deserves reëxamination with the action of subsequent rivers in mind. Again, in various attempts to explain the courses of the Susquehanna and other Appalachian rivers, several authors of twenty or more years ago omitted all consideration of adjustments of streams to structures by processes of migration of divides, because these processes were not then understood. Today such an omission would be held as invalidating all ensuing conclusions.

The newer discussions of the origin and arrangement of valleys must, therefore, attempt to give due attention to both of the groups of considerations indicated above. Postulating the essential principles of uniformitarianism, the life of a stream should be followed from the time when it first gathers on a new land surface through all following time down to the present if we would fully understand the meaning of its position and its behavior. Its active channel-cutting after a time of elevation; the wasting of its valley slopes during a time of still-standing; the search thus undertaken for weak rock structures, along which subsequent streams are developed by headwater erosion; the continual subdivision of drainage areas and the occasional diversion of neighboring streams by the growth of subsequent branches; the adjustment of streams to structures thus accomplished; the meandering of mature, low-grade streams and the wandering of old streams more or less from previously acquired adjustments; the renewal of down-cutting when elevation occurs again; the more thorough adjustment of streams to structures in a second cycle of erosion than is possible in a first cycle; the powerful influence of tilting or deformation on the shifting of divides; the disturbing influences of climatic changes, either toward aridity, humidity or glaciation—these are the more important processes and conditions that must be discussed if a river course is to be seriously investigated. Little wonder that the problem becomes too complex for complete solution in regions of disorderly structure and long existence as dry land.

In regions of no great age and moderate structural complications the explanation and therewith the appreciation of river courses may be accomplished with fair success. The most perfect example that I have found for illustrating the problem is in the neighborhood of Chalôns-sur-Marne, in northeastern France, where the subsequent branches of the Marne and the Aube have diverted certain neighboring consequent streams in the most systematic and symmetric manner. The story is too long for narration here, but it may be found by those who care for details in a forthcoming number of the National Geographic Magazine, in an article entitled "The Seine, the Meuse and the Moselle." Hardly less satisfactory and much more extensive are the examples furnished by the rivers which drain the area of the secondary rocks in eastern England, of which I have given some account in the (London) Geographical Journal for February, 1895.

It is not, however, so much the result of these studies as the bearing of the result upon the postulates on which they are based that I desire to bring before the Society. Certain assemblages of rivers and streams exist in nature. Their peculiar correlations are for a long time not appreciated, if seen. Generally they are not even seen. When at last they are detected and studied out it is found that they find full explanation in accordance with the principles of uniformitarianism, principles that were announced long before any such studies were attempted. The deepening of a valley by its stream is a slow process; the widening of the valley by the wasting of its slopes is still slower; the development of subsequent streams by headwater erosion, the accompanying migration of divides, and the resulting rearrangement and adjustment of waterways are slowest of all. The deepening of a canyon is a rapid process compared to the creeping of a divide. Even the widening of a mature, one-cycle valley is soon done compared to the accomplishment of fully developed adjustments of $(N + 1)$ cycles. Here, if anywhere, the slow processes of uniformitarianism are justified, and the hurried processes of catastrophism are completely at fault.

To attempt to substantiate principles so widely accepted as those of uniformitarianism may seem to some an unnecessary task. It might be compared to adducing new evidence in support of the law of gravitation; but, as the attempt involves the extension of those principles into problems not contemplated by Hutton, Playfair and Lyell and most of their disciples, it may deserve the little time and the few pages that it occupies.

The paper was discussed by B. K. Emerson, N. S. Shaler and W. M. Davis.

The second paper presented was—

ANALYSIS OF FOLDS

BY C. R. VAN HISE

Remarks were made by W. N. Rice and the President.

Professor Emerson made an announcement concerning a geological excursion under his guidance in the afternoon.

The President read the following paper:

CONDITIONS AND EFFECTS OF THE EXPULSION OF GASES FROM THE EARTH

BY N. S. SHALER

It was voted that in calling for the papers which had been deferred or carried over to the end of the program those papers whose authors were absent should be presented only by title.

The following two papers were read by title:

GLACIAL DEPOSITS OF SOUTHWESTERN ALBERTA, IN THE VICINITY OF THE ROCKY MOUNTAINS

BY GEORGE M. DAWSON AND R. G. MCCONNELL

The paper is printed in full in this volume.

DRUMLINS AND MARGINAL MORAINES OF ICE-SHEETS

BY WARREN UPHAM

The paper is printed in full in this volume.

The following paper was read:

*MARTHAS VINEYARD CRETACEOUS PLANTS**

BY ARTHUR HOLLICK

[*Abstract*]

At the New York meeting of this Society, in December, 1889, Mr David White read a paper entitled "Cretaceous Plants from Marthas Vineyard," which was published in abstract in the proceedings of that meeting. The author subsequently published a more extended account in the American Journal of Science for February, 1890, and figured a few of the specimens which were most readily identified. These papers were based upon material collected by the author and Professor Lester F. Ward in the summer of 1889. During the present year all of the material collected was turned over to me for examination and report, in addition to which there were a few specimens obtained personally during the summer of 1893. The general results of the examination of this material it is the purpose of this paper to give.

As is well known, Cretaceous strata, extending from northern New Jersey, through Staten island, Long island and Marthas Vineyard, but much contorted and dismembered, are found in connection with the terminal moraine. Cretaceous material, generally in the form of ferruginous shale, sandstone or concretions, has been discovered, scattered through the moraine also, wherever it has been carefully explored in this region.

The exact stratigraphic relations of the strata, owing to their contortion, are difficult to determine, but theoretically they ought to represent the upper members of the Amboy Clay series, and Professor Ward, in a forthcoming paper† on the Potomac Formation, classes them with Professor Uhler's Albirupean and calls them the "Island series." Now that the specimens have been subjected to critical examination and comparison, it is of interest to note how the paleontologic facts agree with the stratigraphic theory.

I have elsewhere made the comparison between the Cretaceous fossil leaves of

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* Published by permission of the Director of the United States Geological Survey.

† In Fifteenth Ann. Report U. S. Geological Survey.

Long island, Staten island and New Jersey,* and shown that a number of species are common to all these localities. The material from the two localities first mentioned was rather meager, however, and, while some specimens were well defined, the majority were poor, so that there was hardly a fair representation, numerically, with those from New Jersey.

In the material now under consideration there are about 400 specimens, of which about 250 are perfect enough for satisfactory examination. The number of species which these will probably yield is about 100, of which perhaps 15 or more will be described as new. The others are referable, either definitely or provisionally, to previously described species from middle Cretaceous strata—Amboy, Dakota, Atane, Patoot, etcetera—largely the same as have been found on Long island, on Staten island and in New Jersey.

Among the most prominently represented species may be mentioned:

Sphenopteris grevillioides, Heer.
Thinnfeldia lesquereuxiana, Heer.
Juniperus hypnoides, Heer.
Widdringtonites subtilis, Heer.
Frenelites reichii, Ells.
Sequoia ambigua, Heer.
Ficus berthoudi, Lesq.
Ficus krausiana, Heer.
Juglans arctica, Heer.
Laurus plutonia, Heer.
Laurus newberryana, Hollick.
Sassafras acutilobum, Lesq.
Sassafras progenitor, Newb.
Salix protæfolia, Lesq.
Myrsine borealis, Heer.
Diospyros apiculata, Lesq.
Andromeda parlatorii, Heer.
Sapindus morrisoni, Heer.
Sterculia labrusca, Ung.
Sterculia kregeii, Vel.
Paliurus membranaceus, Lesq.
Eucalyptus geinitzii, Heer.
Aralia coriacea, Vel.
Aralia grœnlandica, Heer.
Palæanthus (williamsonia) problematicus, Newb.
Carpolithus spinosus, Newb.
Liriodendropsis simplex, Newb.
Liriodendropsis angustifolius, Newb.
Magnolia longifolia, Newb.
Magnolia glaucoides, Newb.
Magnolia speciosa, Heer.
Magnolia capellini, Heer., etcetera.

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* Paleontology of the Cretaceous formation on Staten island et seq. Trans. N. Y. Acad. Sci., vol. xi, 1892, pp. 96-104; vol. xii, 1892, pp. 28-39. Preliminary contribution to our knowledge of the Cretaceous formation on Long island and eastward et seq. Trans. N. Y. Acad. Sci., vol. xii, 1893. pp. 222-237; vol. xiii, 1894, pp. 122-129; Bull. Torrey Bot. Club, vol. xxi, 1894, pp. 49-65.

New species will probably have to be recognized in the genera *Nelumbo, Cinnamomum, Paliurus, Rhamnus, Ficus, Cassia, Dewalquea, Liriodendropsis, Palæanthus, Ilex, Platanus* and *Betula*.

The conifers and ferns are not yet completely worked up, but will probably yield quite a number of characteristic species.

Making due allowance for the comparative abundance of the Marthas Vineyard material as compared with the paucity of that from Long island and Staten island, we are undoubtedly justified in claiming the closest possible identity between the strata at these localities and to declare them to be the equivalent of the Amboy Clay series.*

It is unfortunate that the Marthas Vineyard material could not be utilized for the differentiation of the strata on that island, but with very few exceptions all the specimens collected in place in the clay strata are absolutely worthless for purposes of identification. All the best specimens are in the ferruginous concretions, whose stratigraphic position is generally in doubt. This is particularly to be regretted, as some of the specimens in clay were found in strata which were thought by some authorities to be of Tertiary age, and a few well defined leaves would probably settle the point. It is also of interest in this connection to note that certain leaves found on Long island were somewhat hesitatingly referred by me to upper Cretaceous species. If the existence of the entire series from the plastic clays upward could be demonstrated, it would be of exceeding interest.

The negative evidence to which these investigations bear witness is also of importance. It will at once be noted that is no instance has there been any indication discovered of the former existence of lower Potomac strata in this region. In discussing this point Professor Ward says: †

> "Here in New Jersey we find the [Amboy] clays in direct contact with the red sandstone of the Newark system as far west as the Sand hills and Ten Mile run. The question is, whether farther out in the formation there is any evidence of older Potomac material underneath the clays"

The fact that no indication of any lower Potomac fossils have yet been found in connection with the moraine would seem to indicate that at least it never existed over any portion of the region which was subject to erosion by glacial action; otherwise these ought to be represented in the moraine in the same manner as are those of the Amboy clays.

Remarks upon this paper were made by President Shaler.

The following two papers were read by title:

ASBESTOS AND ASBESTIFORM MINERALS

BY GEORGE P. MERRILL

SYENITE-GNEISS (LEOPARD ROCK) FROM THE APATITE REGION OF OTTAWA COUNTY, CANADA

BY C. H. GORDON

The latter paper is printed in full in this volume.

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* The posthumous work on the "Flora of the Amboy Clays," by the late Professor J. S. Newberry, is almost through the printer's hands. The editor has corrected and returned proof during the present month. It will be issued as a monograph of the U. S. Geological Survey.

† Loc. cit.

The next paper, read by the author, was entitled:

TITANIFEROUS IRON ORES OF THE ADIRONDACKS

BY J. F. KEMP

[*Abstract*]

The paper opened with a brief statement of the characters of the two kinds of iron ores which are afforded by the region. The merchantable magnetites, both Bessemer and non-Bessemer, occur in a series of gneisses which surround the great central norian mass and its outlying ridges. The ore-bodies are lenticular or pod-shaped in the smaller examples and conform to the usual type, but the larger ones are quite irregular in shape, and may even form apparent beds several miles on the outcrop.

The titaniferous ore-bodies may be grouped in two classes; the one, in basic gabbros, affords low-grade ores, high in titanic oxide and alumina; the other, in pure feldspathic anorthosites, yields richer ores, which are, however, high in titanic oxide. Ore-bodies of the first class have such geologic relations that they are best explained as basic developments of a gabbro magma. The Split Rock mine, near Westport, is the best illustration and is easily accessible. The second class is almost limited to the vicinity of lake Henderson and lake Sanford, in the heart of the central norian area. The wall-rock is massive, unbrecciated anorthosite, and is almost entirely formed of large, blueish black crystals of labradorite, which lack the crushed borders that give the "mortar structure" to most of the Adirondack anorthosites.

The ore-bodies are enormous, and by means of the dipping compass one series that crosses lake Sanford has been traced as much as two miles, with a width for the area showing attraction of several hundred feet. Trenches or costeaning pits dug many years ago exhibited ore and anorthosite in streaks.

The massive ore contains great numbers of labradorite crystals even up to 20 centimeters in diameter of a dark green color from innumerable inclusions of small pyroxenes. Each included feldspar is surrounded by a "reaction rim" from 5 to 10 millimeters across, consisting of brown hornblende and biotite. From the nature of these included labradorite crystals and the lack of evidence of dynamic metamorphism in the wall-rock, the argument was made that the ores are segregations from an igneous magma formed during the process of cooling and crystallization.

In conclusion, a few notes were given regarding recent successful experiments in smelting them and on the peculiar excellence of the resulting iron.

In discussion, C. R. Van Hise mentioned the similar bodies of titaniferous ores in the gabbros of lake Superior, adding, however, that there had been some infiltration of iron oxide since their formation.

The paper was discussed by C. R. Van Hise and the President.

The following paper closed the list:

DECOMPOSITION OF ROCKS IN BRAZIL

BY JOHN C. BRANNER

The paper was discussed by I. C. Russell, C. R. Van Hise, H. T. Fuller and the President. It is printed in full in this volume.

An invitation to the Society to visit the United States arsenal was announced.

Upon motion of J. F. Kemp, a resolution was voted of thanks to the City Library Association, Reverend William Rice, Librarian, and to the Local Committee of the American Association for the Advancement of Science for their hospitality and kindness.

The Seventh Summer Meeting was declared adjourned.

Register of the Springfield Meeting

The following Fellows were in attendance upon this meeting:

G. H. Barton.
Florence Bascom.
J. C. Branner.
W. B. Clark.
W. O. Crosby.
W. M. Davis.
B. K. Emerson.
H. L. Fairchild.
A. C. Gill.
C. H. Hitchcock.
W. H. Hobbs.
Arthur Hollick.
E. O. Hovey.
J. P. Iddings.
J. F. Kemp.
J. R. Macfarlane.
V. F. Marsters.
Charles Palache.
J. H. Perry.
W. N. Rice.
I. C. Russell.
N. S. Shaler.
J. P. Smith.
J. W. Spencer.
C. R. Van Hise.
L. G. Westgate.
I. C. White.
R. P. Whitfield.
H. S. Williams.
A. A. Wright.

Fellow-elect

O. C. Farrington.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 7, PP. 17-30 NOVEMBER 14, 1895

DRUMLINS AND MARGINAL MORAINES OF ICE-SHEETS

BY WARREN UPHAM

(Presented before the Society August 28, 1895)

CONTENTS

INTRODUCTION.

The chief characteristic of the present stage of investigations of the Ice age and its glacial and modified drift deposits seems to consist in the search, through observations and study, for explanations of the methods in which the ice-sheets of North America, northern Europe, Patagonia, and other glaciated areas, acted in eroding, mingling, transporting and depositing the various drift formations.

All the diverse phases of the till or ground moraine, also called boulder-clay, from its heterogeneous materials, and including much englacial drift, which was allowed to fall loosely on the ground from the ice during its stages of retreat, are classed together as direct products of the action of land ice, without modification by the assorting, transporting and stratifying agency of streams and lakes formed by the glacial melting and accompanying rains. Most drumlins in their entire mass, and all others in their superficial part, consist of till, an unstratified deposit of intermingled boulders, gravel, sand and clay, in which usually the largest ingredient by measure is the very finely ground rock flour of the glacial grist. Though called clay, the rock flour, on areas of sandstone, granites, gneisses or quartzose schists, is made up principally of exceedingly finely comminuted quartz particles.

Likewise the marginal moraines, which record the history and work of the ice-sheets during the fluctuating stages of their wavering final recession, are, along the greater part of their extent, composed mainly of till, with multitudes of boulders. Nearly everywhere also they inclose occasional lenticular or irregular beds of gravel and sand, with here and there superficial knolls and short ridges of similar gravel and sand, called kames. The inner stratified beds and the kames were laid down by streams from the ice melting and from rains, while the till of the moraines was borne and pushed forward by the slowly advancing ice to the limit where the equilibrium of climatic conditions temporarily held the glacial border nearly stationary during any series of years. Less frequently some considerable extent of the marginal drift belt, though amassed in hills 100 to 200 feet high, consists almost wholly of modified drift, being stratified gravel and sand, with only rare inclosed or superficial boulders, forming a prolonged series of gigantic, massively rounded kame deposits, as in the great frontal moraine on Long island, from Roslyn east to Napeague, a distance of about 75 miles.

The purpose of the present paper is to inquire how the ice amassed its prominent, round or oval, and sometimes more elongated, hills of till called drumlins, and how it brought and heaped up the till in its equally conspicuous, but more confusedly grouped, marginal moraine hills, distinguished notably by their irregularity of contour, abundant boulders and extension in series which are traced hundreds and even thousands of miles, from Nantucket, Marthas Vineyard and cape Cod to Wisconsin, Iowa, Minnesota, South and North Dakota, Manitoba and the northwestern plains of Assiniboia, Saskatchewan, and Alberta. Both the drumlins and the moraines are found referable to the Champlain epoch or closing part of the Glacial period, when the country, heavily laden by the ice-sheet, had sunk from its high preglacial and Glacial elevation, being depressed mostly somewhat below its present height, so that the reign of the Arctic climate, which had deeply covered the land with snow and ice, was rapidly brought to an end by mild temperate conditions nearly like those of the present time in the same latitudes.

For Europe, as well as North America, the drumlins and moraines are shown to be referable to this final Champlain epoch of the Ice age; and the whole history of the Glacial period, in its beginning, successive stages, and end, appears to have been, in a general way, synchronous throughout its series of stages on the two continents. During the growth and culmination of the ice-sheets in both North America and Europe the conditions of glacial action in transportation and deposition of drift were very unlike those of the ensuing Champlain epoch, to which the drumlins and marginal moraines chiefly belong. By the depression of the land and consequent return of a temperate climate the ice was rapidly melted away, with steeper frontal gradients, more powerful currents, and more vigorous drift accumulation in the drumlin and moraine hills than during the earlier and longer part of the Ice age, while the land had a high altitude and severely cold climate.

Greenland now in a considerable degree represents the time of growth and maximum extent of the Pleistocene ice-sheets; but Alaska, with its generally receding glaciers, and most notably the Malaspina ice-sheet, having a drift-covered and forest-bearing border, partially illustrates the conditions of the Champlain epoch.

NORTH AMERICAN AREAS OF DRUMLINS.

Besides the frequent arrangement of the drumlin hills and ridges of till in groups and somewhat definite belts, which are from a few miles to 10 or 20 miles wide, lying approximately parallel with the general course of neighboring marginal moraines, while intervening belts or irregular areas are destitute of drumlins, a still more noteworthy feature of their geographic distribution is found in their occurring thus upon some extensive districts, while they are utterly wanting on larger portions of the great glaciated areas of North America and Europe.

Mr Robert Chalmers has observed numerous drumlins on the east side of lake Utopia and between the Magaguadavic and Saint Croix rivers in Charlotte, the most southwestern county of New Brunswick.* Under the name "whalebacks," Mr G. F. Matthew describes these and other drumlins in the southern part of this province on an area extending from the Saint Croix about 90 miles east to Upham township.†

Drumlins are reported in Maine by Professor George H. Stone, the lenticular type prevailing in the western part of the state, while toward the east they also take the form of long ridges. In size and numbers, however, they are described as inferior to the drumlins of New Hampshire, Massachusetts, and New York.‡

The earliest mapping of drumlins in this country was done by the writer in 1878, under the direction of Professor C. H. Hitchcock, for the Geological Survey of New Hampshire.§ Nearly 700 drumlins were noted in the southern half of this state, but throughout its northern half these drift accumulations are absent or very rare. Some 130 drumlins in adja-

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* Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, vol. iv, for 1888-'89, p. 23 N.

† Geol. and Nat. Hist. Survey of Canada, Report of Progress for 1877-'78, pp. 12-14 EE.

‡ Proc. Bos. Soc. Nat. Hist, vol. xx, 1880, p. 434. Proceedings of the Portland Society of Natural History, March 11 and Nov. 21, 1881.

§ Geology of N. H., atlas and vol. iii, 1878, pp. 285-309, with heliotype.

cent portions of northeastern Massachusetts and southwestern Maine were also noted on this map.

Professors Shaler, Wright, Hitchcock, and Davis, and the present writer, have described the drumlins of Boston and neighboring areas, where they are admirably developed.[*] During the years 1890 to 1893 the drumlins of the entire state of Massachusetts have been mapped and carefully studied by Mr George H. Barton, under the direction of Professor N. S. Shaler, for the United States Geological Survey.[†] Their total number is found to be nearly 1,800, counting, as in New Hampshire, the separate, rounded summits of compound drumlin aggregations, where two or three of these hills, or sometimes more, are merged together at their bases.

From the vicinity of Spencer, Massachusetts, a series of abundant drumlins, according to Davis, extends south to Pomfret, in northeastern Connecticut. They probably also occur plentifully in other parts of this state, reaching southward to Long Island sound, for Round hill, in Orange, near New Haven, described by Professor J. D. Dana, appears to be a drumlin.[‡]

New York has a magnificent area of drumlins, perhaps the most interesting in the United States, which stretches more than 60 miles, from Syracuse westward nearly to Rochester, lying between the south side of lake Ontario and the Finger lakes.[§] These hills are well seen along the New York Central and West Shore railroads. Another area of drumlins, occurring in less profusion and less diversity of forms, lies in Jefferson county, between the east end of lake Ontario and the Adirondacks.[‖]

In the drift-covered northern part of New Jersey drumlins are infrequent, only two examples being mentioned by Professor R. D. Salisbury in his preliminary paper on the Pleistocene formations of that state.[¶]

No drumlins have been found in Ohio, Indiana, and Illinois, by Mr Frank Leverett, Professor G. F. Wright, and others, who have thoroughly

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[*] N. S. Shaler: Proc. Bost. Soc. Nat. Hist., vol. xiii, 1870, pp. 196–204. Illustrations of the Earth's Surface: Glaciers, 1881, pp. 60–63. U. S. Geol. Survey, Seventh Ann. Rep. for 1886, pp. 321, 322; Ninth Ann. Rep. for 1888, pp. 550, 551.

G. F. Wright: Proc. Bost. Soc. Nat. Hist., vol. xix, 1876, p. 58, and vol. xx, 1879, p. 217. The Ice Age in North America, 1889, chapter xi.

C. H. Hitchcock: Proc. Bost. Soc. Nat. Hist., vol. xix, pp. 63–67.

W. M. Davis: Illustrations of the Earth's Surface: Glaciers, text describing plate xxiv. Proc. Bost. Soc. Nat. Hist., vol. xxii, 1882, pp. 34, 40–42. Science, vol. iv, pp. 418–420, Oct. 31, 1884. Am. Jour. Sci., III, vol. xxviii, pp. 407–416, Dec., 1884.

Warren Upham: Proc. Bost. Soc. Nat. Hist., vol. xx, 1879, pp. 220–234; vol. xxiv, 1888, pp. 127–141; and same vol. xxiv, 1889, pp. 228–242. Am. Jour. Sci., III, vol. xxxvii, pp. 359–372, May, 1889. Am. Geologist, vol. x, pp. 339–362, Dec., 1892.

[†] Bull. Geol. Soc. Am., vol. 6, 1894, pp. 8–13.

[‡] Am. Jour. Sci., III, vol. xxvi, 1883, pp 357–361.

[§] L. Johnson: Trans. N. Y. Acad. Sci., vol. i, 1882, pp. 78–80; Annals, do., vol. ii, pp. 249-266, with map. D. F. Lincoln: Am. Jour. Sci., III, vol. xliv, pp. 290–301, Oct., 1892.

[‖] Bull. Geol. Soc. Am., vol. 3, 1892, p. 142.

[¶] Geol. Survey of New Jersey, Ann. Rep. for 1891, p. 74.

examined that area, mapping its marginal moraines and other drift deposits.

Next northwestward, however, drumlins are again encountered in great abundance and variety in the eastern part of Wisconsin. Professor T. C. Chamberlin estimates their number in that district and the adjoining northern peninsula of Michigan to be not less than 5,000.*

Throughout a large region extending thence northwestward, comprising Minnesota, northern and central Iowa, South and North Dakota, and southern Manitoba, Professor N. H. Winchell's and my own exploration and mapping of the drift and its marginal moraines have failed to discover any of the peculiarly moulded masses of till classed as drumlins.

Beyond this region drumlins have been reported only by Mr J. B. Tyrrell in lake Winnipegosis, where they form groups of lenticular and elongated low islands,† and similarly in Cree lake and the country southeast of lake Athabasca, from 400 to 500 miles still farther northwest.‡

Accumulation of Drumlins from englacial Drift.

Whenever the warm climate terminating the Glacial period extended unchecked through many years, the depth of the ablation or superficial melting of the outer part of the ice-sheet was probably not less than 15 to 25 feet each summer, as has been observed on the Muir glacier, in Alaska, and on the Mer de Glace, in Switzerland. At such rates of melting any district enveloped by ice 2,000 to 4,000 feet thick, as was true of the central portions of New England and doubtless also of a broad belt thence west to the Laurentian lakes and to Minnesota and southern Manitoba, would be uncovered in one or two centuries, and the recession of the Glacial boundary would average probably a half mile or more yearly.

During any long series of years when the ice-sheet was being thus rapidly melted, its outer portion to a distance of probably five or ten miles from its boundary, being reduced by ablation to a thickness ranging from 100 or 200 feet near the edge upward to 1,000 feet or more, would bear on its surface, especially in the valleys and hydrographic basins of its melting, much drift which had been before contained in the higher part of the ice.§ Only scanty englacial drift, mainly consisting of boulders borne away from hills and mountains, appears to have existed at altitudes exceeding 1,000 or 1,500 feet; but all the lower ice probably contained an increasing proportion of detritus and boulders which had been

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* Proc. Am. Assoc. Adv. Sci., vol. xxxv, for 1886, p. 204.

† Geol. and Nat. Hist. Survey of Canada, Ann. Rep., new series, vol. iv, for 1888–'89, p. 22A. Bull. Geol. Soc. Am., vol. 1, 1890, p. 402.

‡ Geol. Survey of Canada, Ann. Rep., new series, vol. vi, for 1892–'93, p. 15A (1892). Am. Geologist, vol. xi, pp. 132, 175, Feb. and March, 1893.

§ Bull. Geol. Soc. Am., vol. iii, 1892, pp. 134–148; vol. v, 1894, pp. 71–86. Am. Geologist, vol. viii, pp. 376–385, Dec., 1891; vol. x, pp. 339–362, Dec., 1892; vol. xii, pp. 36–43, July, 1893.

brought into it from below by upward movements due to faster flow of the central and upper glacial currents than of those retarded by friction on the ground. The thinned border of the ice-sheet upon the belt having a remaining thickness of less than 1,000 feet would therefore become covered with drift, as Russell has described the borders of the Malaspina glacier or ice-sheet, which stretches from the Mount Saint Elias range to the ocean.

At many times the general recession of the ice-sheet was temporarily interrupted. The return of a prevailingly cold climate for several decades of years, or occasionally, as we may suppose, for a century or more, brought increased snowfall, which sufficed to hold the ice boundary nearly stationary, perhaps frequently first having pushed it again a considerable distance forward. The thick ice lying far back from the border may then have flowed over its previously thin and drift-covered outer belt, aiding with the new snowfall to envelop the once superglacial drift stratum within the ice-sheet. With the increased thickness and steeper gradient of the outer part of the ice-sheet while the recession of its boundary was slackened, wholly stopped, or changed to a re-advance, due mainly to very abundant snowfalls, much drift which had been formerly exposed on the ice surface would become again englacial, so that a stratum of drift several feet thick might be enclosed in the ice at an altitude increasing inward from less than 50 feet to 500 feet or more.

The upper current of the thickened ice above the englacial bed of drift would move faster than that drift, which in like manner would outstrip the lower current of the ice in contact with the ground. Close to the glacial boundary, whether it halted and even re-advanced or merely its retreat was much slackened but did not entirely cease, the upper part of the ice must have descended over the lower part. This differential and shearing movement, as I think, gathered the stratum of englacial drift into the great lenticular masses or sometimes longer ridges of the drumlins, thinly underlain by ice and overridden by the upper ice flowing downward to the boundary and bringing with it the formerly higher part of the drift stratum to be added to these growing drift accumulations. The courses of the glacial currents and their convergences to the places occupied by the drumlins were apparently not determined so much by the topography of the underlying land as by the contour of the ice surface, which under its ablation had become sculptured into valleys, hills, ridges, and peaks, the isolation of the elevations by deep intervening hollows being doubtless most conspicuous near the ice margin.

Variability in the rate and manner of departure of the ice-sheet may well account for the geographic distribution of the drumlins, as certain areas of their abundance, neighboring tracts where they are more scattered, and the rare occurrence of lone drumlins, yet of large size and typical form. With much englacial drift gathered in layers and patches in the lower part of the ice-sheet, the inequalities of ablation and superglacial drainage, when extended at certain times over a somewhat broad belt of the ice border, may have produced convergent currents of the lower ice sufficient for amassing these hills in all their variety of grouping and occasional solitary occurrence.*

NORTH AMERICAN MARGINAL MORAINES.

In the subdivision of the Glacial period by Geikie, Chamberlin and others, the time of principal accumulation of marginal moraines is regarded as an epoch distinct from the previous portions of the Ice age; and Chamberlin has named the earlier divisions of this period, when the North American ice-sheet reached its culmination, the Kansan and Iowan stages, while the later moraine-forming time is called the Wisconsin stage, from the magnificent development of the moraines in eastern Wisconsin.† Between these glacial stages, which appear well recognizable and synchronous in North America and Europe, these authors suppose that there were prolonged interglacial epochs when the ice-sheets were in large part or wholly melted away. Instead of this view, the Ice age seems to me to have been essentially a single glacial epoch, with moderate fluctuations of the ice borders during both the growth and the wane of the ice-sheet. The marginal moraines I consider to have been very rapidly formed while the ice was retreating from its Iowan stage, with no important general re-advance dividing the Iowan from the Wisconsin or moraine-forming stage.

From my studies of the glacial lake Agassiz, whose duration was probably only about 1,000 years, the whole Champlain epoch of land depression, the departure of the ice-sheet because of the warm climate so restored, the accumulation of the great marginal moraines during pauses of the glacial recession, and most of the reëlevation of the unburdened lands, appear to have required only a few (perhaps four or five) thousand years, ending about 5,000 years ago. This closing part of the Glacial period, when the moraines were being amassed, was apparently far shorter than its earlier stages of oncoming and culmination.

Three or four of the most prominent moraines of the country on each side of lake Agassiz were formed contemporaneously with the highest beach of the glacial lake, but the formation of that beach could not have

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* More detailed statements of this theory are given in the Am. Geologist, vol. x, pp. 339–362, Dec., 1892, and in Proc. Bost. Soc. Nat. Hist., vol. xxvi, pp. 2–17, for Nov., 1892, with ensuing discussion by Professor W. M. Davis and Mr George H. Barton, pp. 17–25. A later note which I published in the Am. Geologist, vol. xv, pp. 194, 195, March, 1895, I should now wish to change so far as it suggested departure from the earlier papers here cited.

† The Great Ice Age, third edition, 1894. Journal of Geology, vol. iii, pp. 241–277, April–May, 1895.

occupied more than a tenth part of the whole duration of the lake, or by rough estimate a hundred years, more or less. The conspicuous belts of morainic hillocks, hills and ridges, consisting of very bouldery till, frequently with much kame gravel and sand, of which I have mapped twelve in Minnesota and North Dakota, and Leverett a still larger number in Illinois, Indiana and Ohio, were therefore probably each amassed within a few years, or at the longest probably no more than 25 or 50 years, even for the accumulation of the prominent Leaf hills, rising 200 to 350 feet above the surrounding country. How could such rapid drift transportation and deposition take place? If this question can be satisfactorily answered, with reference of the moraines, both in North America and Europe, to the time of retreat from the Iowan glacial boundaries, a chief argument, which has been much relied upon by the defenders of the theory of two or several distinct glacial epochs, will be set aside.

Conditions of Formation of marginal Moraines.

Englacial drift had been carried by the ice currents in some important amount into the basal quarter or third of the ice-sheet; and when the superficial melting or ablation reduced the ice border to a less thickness, this drift was gradually uncovered upon the ice surface. The rates of ascent of the frontal slope may be assumed, in accordance with the upper limits of glacial action on mountains, and after careful consideration of the surface gradients of the Alpine glaciers and of the Greenland ice-sheet, as 400 feet in the first mile, 200 feet in the second mile, and 150, 120, 100, 85, 75, 67, 60 and 55 feet in the third to the tenth miles, respectively, attaining an altitude of 1,312 feet, or about a quarter of a mile. Thence we may suppose the ascent to average 50 feet per mile for the next nine miles, by which the altitude of a third of a mile, the probable upper limit of the englacial drift on any area where the ice-sheet had been about a mile thick, would be reached.

On areas where the ice-sheet built up large marginal moraines, and also wherever its drainage from ablation brought exceptional volumes of modified drift, or stratified gravel, sand and clay, directly supplied by the ice melting, we must believe that the amount of the englacial drift was greater than on other tracts having smaller moraines and little modified drift. Let us assume, therefore, for the definite illustrative case in which we are seeking to account for prominent moraine accumulations, that the total englacial drift in the lower third or 1,760 feet of the ice-sheet was equal to a thickness of 15 feet. This may have been distributed, as shown in the accompanying table, so that the basal ice stratum, 400 feet thick, terminating within the first mile from the front, should contain 5 feet of englacial drift; the stratum, 200 feet thick, terminating in the second mile, 2 feet of drift; the 150 feet of ice terminating in the third mile, 1½ feet of drift; the fourth mile's ice stratum, 120 feet thick, 1 foot of drift; and the stratum of 100 feet in the fifth mile, seven-tenths of a foot. The amount of englacial drift above the altitude of 970 feet, reached at the end of five miles, would be about 5 feet in a thickness of about 800 feet of ice, the upper limit, as before noted, being assumed to be 1,760 feet above the land surface.

The rate of ablation of the ice in the warm summers of the Champlain epoch, with alternating sunshine and still more efficient rains, probably averaged from two to four inches daily during 200 days of the warm portion of each year. In the remaining five and a half months we may suppose that the snowfall and ablation counterbalanced each other, while the ice advance, though diminished on account of the lower temperature, would produce some thickening of the border. Rarely the border thickening during many years of prevailingly low temperature would accumulate drumlins in the manner before described. Frequently when a series of years had a small mean rate of ablation, the ice front remained nearly stationary, giving the conditions necessary for the formation of a marginal moraine; but when the ablation was more rapid, no belt was occupied by the front so long as to be marked by morainic hills and ridges. An average ablation of two inches per day during 200 days of each year may be assumed as permitting the front to remain on the same line, or with advances and recessions not exceeding a half mile or one mile from that line. The resulting moraine would be heaped irregularly on a belt one to two miles wide.

Conditions of morainic Drift Accumulation.

Ice stratum terminating in successive miles.	Ascent of ice surface.			Glacial advance.		Morainic drift, in feet.		
	Feet per mile.	Total.	Ratio.	Feet daily in summer.	Miles in 30 years.	Englacial.	Becoming superglacial in 30 years.	Previously superglacial.
1	400	400	1:13	2.1	2.5	5.0	12.3	10.0
2	200	600	1:26	4.3	5.3	2.0	10.6	8.0
3	150	750	1:35	5.8	6.7	1.5	10.0	6.5
4	120	870	1:44	7.3	8.7	1.0	8.7	5.5
5	100	970	1:53	8.8	10.4	0.7	7.3	4.8
Total average thickness of moraine from these five miles, 83.7 feet, if amassed on a belt one mile wide.							48.9	34.8

To supply the ice by onflow equivalent to the ablation of two inches daily in summer upon the first mile from the frontal line would require an average forward current of 26 inches daily for the lowest 400 feet of the ice-sheet. On the land bed, where it was impeded by friction, the rate was very small, thence gradually increasing upward. In the second mile the ice would retain its height unchanged under this ablation by an average onflow of 4.3 feet daily for the stratum of ice 200 feet thick terminating in that mile; the third mile would require for its stratum of 150 feet a daily current of 5.8 feet, and the fourth and fifth miles would require currents, respectively, of 7.3 and 8.8 feet. Between nine and ten miles from the ice front, at an altitude of 1,257 to 1,312 feet, the ablation could be offset only by a current of 16 feet daily. By such currents, urged forward by the great weight of the more central and increasingly thicker part of the ice-sheet, the superficial wasting of the ice border would be evenly balanced, holding, therefore, the nearly steady frontal line indispensable for abundant marginal drift deposition. The gradients thus assumed for the ice surface near its boundary are probably twice as steep as they were during the earlier stages of predominant ice accumulation. Hence, with the greatly increased Champlain temperature, the rates of glacial movement were perhaps five or even ten times faster than during the maximum stage of glaciation.

If the outermost five miles of the ice, having the conditions here assumed, remained in essentially unchanged position thirty years, the total volume of drift there becoming superglacial would be equivalent to about 50 feet on a width of one mile. With the previously superglacial drift of the same outer belt of the ice, which, like the foregoing, must have been carried forward to the boundary, there would be a thickness of about 85 feet; and with all received in the same time from the more distant part of the ice surface, up to ten miles from the margin, the total terminal mass of drift would equal at least an average of 100 feet on a belt one mile wide. This amount, amassed by the small frontal oscillations of the ice so as to form irregularly grouped hills and ridges, separated, as those of the moraines usually are, by deep and wide hollows, would constitute a morainic belt probably unsurpassed either in North America or Europe. Under the same conditions, a small but distinct moraine might be formed in only five or ten years; or, where the ice-sheet had less englacial drift, as a quarter or only a tenth as much, the smaller parts of a moraine belt would be made during the same thirty years in which elsewhere its most prominent portions were being deposited.

Drumlins and Moraines both referable chiefly to the Champlain Epoch.

From this discussion of the origin of drumlins and marginal moraines it will be seen that their accumulation belonged chiefly to the Champlain epoch of land depression, restored warmth and mainly rapid glacial retreat, interrupted by times when the ice-sheet for several years or decades of years held a nearly stationary position. According to the supposition that two inches of daily summer ablation was approximately equaled by the glacial onflow, whenever the ablation was at a faster average rate, as three or four inches daily, the ice receded, depositing the smoother till sheets between the hilly marginal moraine belts.

During the stages of ice accumulation, up to the maximum of the glaciation and to the Iowan stage, I think that the ice-sheet eroded much drift on its central area and bore it forward in the basal quarter or third of the whole thickness of the ice, depositing much of it, however, as subglacial till within fifty miles, more or less, back from its front. When the final recession of the ice carried its border gradually backward over all its area, I believe that the process of subglacial drift deposition continued, forming the ground moraine or lower part of the till progressively as the ice border withdrew, and now and again, under exceptional climatic conditions, amassing much of this till in drumlins. The part of the drift which had remained englacial, when the frontal line in its retreat reached the place of a temporary pause, permitting a marginal moraine to be formed, was then borne forward in the manner described to the boundary.

Only with a rate of ablation much faster and with glacial currents much stronger than those of the Arctic regions or of the continental ice-sheets during their time of accumulation under the severe climate of their high plateau elevation, in short, only during the Champlain epoch, when the land had sunk from its preglacial and Glacial altitude, both in America and Europe, could noteworthy drumlins and peripheral moraines be amassed. They record on each continent the definite closing epoch of the Glacial period.

European Drumlins and Moraines.

We owe the earliest observations and descriptions of drumlins to Kinahan and Close, in Ireland, and to Shaler, in Massachusetts. These remarkable hills of till are admirably developed in portions of Ireland, Scotland, and northern England. To what extent they exist on the glaciated areas of northern Germany, Russia, and Scandinavia, appears not yet to be clearly ascertained.

During nearly forty years, from the first announcement by Agassiz of his theory that the general drift-sheets of Europe and North America were produced by vast sheets of land ice, their marginal moraines remained unrecognized. Their true character was first made known somewhat less than twenty years ago by Clarence King on the Elizabeth islands of southeastern Massachusetts, Chamberlin in Wisconsin, Lewis and Wright in Pennsylvania, Cook and Smock in New Jersey, and the present writer on Long island, Marthas Vineyard, Nantucket, and cape Cod. After the grand development of these moraines of the North American ice-sheet had been well explored in their main features from the Atlantic coast to North Dakota, the first discoveries of the similar marginal moraines of the British and European ice-sheets were made less than ten years ago by two American glacialists, who were specially qualified for these observations by their previous work in the United States, namely, Professor H. Carvill Lewis, in Great Britain and Ireland, and Professor R. D. Salisbury, in Germany. It is now ascertained that there are well defined belts of morainic drift hills in southern Sweden, Denmark, northern Germany, and Finland. The most conspicuous German moraine belt is named the Baltic ridge, and the waning ice-sheet at the stage of its formation is known as the great Baltic glacier. All these moraines appear to belong to the same declining part of the Ice age, being correlative with the Wisconsin stage of glaciation in the northern United States.*

Recognition of the Champlain Epoch in Europe.

The general contemporaneousness of the Glacial period on the opposite sides of the North Atlantic ocean had been long accepted as probable, but its demonstration and the identification of the corresponding parts of the Ice age, having the same sequence on the two continents, were first made known last year by the studies of Geikie and Chamberlin in the new third edition of "The Great Ice Age," and by their later papers this year in the Journal of Geology, as already cited. Not only are the Kansan and Iowan stages of culmination of the ice-sheets closely alike for these widely separated great areas, but also the land depression of the Champlain epoch in both North America and Europe brought marine submergence of coastal tracts and caused rapid disappearance of the ice-sheets, with the formation of their drumlins and marginal moraines. These two continents were included in the portion of the earth's crust which twice experienced far extended epeirogenic movements, first of high uplift, bringing the cold climate and snow and ice accumulation of the Glacial period, and afterward of depression somewhat lower than now, whereby the vast ice fields were melted away.

Contrast of the Growth and Decline of the Pleistocene Ice-sheets in their Deposition of Drift.

During the growth and maximum advance of the ice-sheet on each continent the border of the drift along the greater part of its extent was

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* For a correlation of the stages of the Ice age in North America and Europe leading to the foregoing explanation of the rapid accumulation of the marginal moraines, see the Am. Geologist, vol. xvi, pp. 100-113, Aug., 1895, with maps of the Kansan, Iowan, and Wisconsin boundaries of the North American and European ice-sheets.

laid down as a gradually attenuated sheet, with neither moraines nor drumlins. After the Kansan or culminating stage the ice retreated and the drift underwent much subaërial erosion and denudation during the Aftonian interglacial stage. Renewed accumulation and growth of the ice in the Iowan stage is again represented by an overlying thin and somewhat even sheet of drift near the limits of that glacial advance, which mostly failed to reach the earlier boundary.

Next came the Champlain epoch of general depression of the ice-burdened lands both east and west of the North Atlantic, when the ice again retreated, but apparently at a much faster rate than before, with great supplies of loess from the waters of its melting. Moderate reëlevation of the tracts earliest uncovered from the ice almost immediately ensued, and a permanent uplift from the Champlain subsidence thence advanced like a wave from the borders toward the center of each of these continental glaciated areas as fast as the ice front retreated. During this glacial recession prominent moraines, in notable contrast with the smooth and comparatively thin outer drift, were amassed in many irregular but roughly parallel belts, where the front at successive times paused or readvanced under secular variations in the prevailingly temperate and even warm climate by which, between the times of formation of the moraines, the ice was rapidly melted away. Occasionally, too, the retreating ice became much thickened near its boundary, giving the peculiar conditions of accumulation of the drumlins, which are somewhat analogous with the marginal moraines. The smooth but steep drumlins are subglacial aggregations of till heaped near the mainly waning ice front, while the rougher moraine hills are its marginal deposits. Both were dependent on secular variations of the average climatic conditions during the Champlain epoch, requiring a few years or decades of years for their formation, according to their varying size, the abundance or scantiness of the englacial drift on and near their areas, and the vigor or feebleness of the glacial currents.

Comparison of present Ice Action in Alaska and Greenland.

The Malaspina ice-sheet in Alaska has been slowly retreating, like the Muir glacier and others of that country, during the past hundred years or probably much longer. On all its border for a width of a few miles, now thinned perhaps to a quarter part or less of the earlier depth, the waning ice is covered by its formerly englacial drift; but, in that cold climate, the glacial movement is so very slow that forest trees, with luxuriant undergrowth of shrubs, and many herbaceous flowering plants, grow on this drift lying upon hundreds of feet of ice as revealed by stream channels. Advancing toward the interior, the explorer soon comes upon higher clear ice and névé, having risen above the plane of the englacial débris, excepting along the course of belts of medial surface morainic drift, swept outward from spurs of the mountains. This ice-sheet partially suggests the conditions of the moraine-forming southern portion of the North American and European ice-sheets during the Champlain epoch; but these had a climate much warmer than that of Alaska, with consequent far more rapid ablation and stronger glacial currents.

In Greenland. on the other hand, the mean temperature has probably been gradually lowered during several centuries past, since the prosperous times of the Norse colonies 900 to 500 years ago. A great ice-sheet, 1,500 miles long with a maximum width of 700 miles, covers all the interior of Greenland; and, although now its extent is less than during the Glacial period, it has doubtless held its own or mainly somewhat increased during several hundred years. While the snow and ice accumulation is predominant, no englacial drift becomes superglacial; but in the region of Inglefield gulf Chamberlin finds the frontal ice-cliffs well charged with englacial débris to a third or half of their total heights of 100 to 200 feet or more. The same ratio of the lower part of the ice-sheet containing drift would quite certainly give it a thickness of 1,000 to 2,000 feet in the deeply ice-covered central portion of Greenland. Other features especially noted are the very distinct stratification of the ice and its differential forward motion, producing not only this stratification, but also sigmoid folds and overthrust faults, where the upper layers move faster than the lower, and these in turn faster than the friction-hindered base. In just the same way, as shown in the foregoing pages, the accelerated currents of the waning ice-sheet during the temperate Champlain epoch overrode each other in succession from the highest to the lowest on the moraine-forming border, bearing a great amount of superglacial drift to the margin, and under certain favorable conditions heaping massive drumlin hills beneath the marginal part of the ice.

If a mild, temperate climate could bring to Greenland the conditions of the Champlain epoch, its thick ice-sheet in the interior under rapid ablation would fully illustrate, as the Malaspina glacier even now does in a considerable degree, the formation of the great series of morainic drift hills and the diversely grouped drumlins which mark stages in the retreat of the continental ice-sheets.

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GLACIAL DEPOSITS OF SOUTHWESTERN ALBERTA IN THE VICINITY OF THE ROCKY MOUNTAINS

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(*Presented before the Society August 28, 1895*)

CONTENTS

INTRODUCTION.

The western plains and the Rocky Mountain region of Canada undoubtedly constitute one of the most important fields of investigation in connection with the glacial period in North America. The area there characterized by glacial deposits is an enormous one, but the facts derived from it have so far been accorded comparatively little weight in the construction of hypotheses for the continent. Of these hypotheses those in best standing have grown up chiefly during the detailed study of the southern portion of the glaciated region of the east. Distance, and a general unfamiliarity with the somewhat complex physical features of this western region, have undoubtedly prevented a ready appreciation of its phenomena, but these also must in the end be fully reckoned with before satisfactory conclusions of a general kind can be definitely reached. In former papers* the writer has endeavored to combine the observations made by himself and others in the Cordillera and adjacent parts of the Great plains in a common scheme, although one admittedly of a char-

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*Am. Geologist, Sept., 1890, p. 153. On the Physiographical Geology of the Rocky Mountain region in Canada. Trans. Roy. Soc. Can., vol. viii, sec. 4, 1890, p. 4.

acter entirely tentative. In the following notes his purpose is merely to amplify previous observations on a particularly interesting part of this western region by the addition of new facts, given, as far as possible, apart from any theoretical considerations whatever. In the concluding pages, however, an attempt is made to indicate the more obvious deductions which appear to flow directly from the examination of the particular district in question.

In a report by the writer on the southern portion of the district of Alberta,* the principal facts then ascertained of the "superficial geology" are given, but the work upon which that report was based was directed chiefly to the "solid geology" of the country, and details respecting the superficial geology were as far as possible eliminated in the interests of brevity. Since the publication of that report great advances have been made in our knowledge of the glacial phenomena of the northern part of the continent, some of which seemed to render the region particularly referred to in this paper one of especial importance as the meeting place of the deposits (whether immediately or proximately derived) of the Cordilleran and Laurentide ice-sheets. Thus it became desirable that an attempt should be made to further investigate this region and to test the previous observations and conclusions. With this object in view, a couple of weeks in the early part of the summer of 1894 were devoted chiefly to a critical examination of the superficial deposits of that part of southwestern Alberta adjacent to the eastern slopes of the Rocky mountains. The writer was accompanied by Mr R. G. McConnell, who had previously acted as his assistant in the same field, and, while he assumes the responsibility for the statements made in the sequel, those observations made by Mr McConnell will be given under his own name and in his own words. He would further take this opportunity of acknowledging the value of Mr McConnell's coöperation, and of stating that in regard to the observations of fact, at least, there is complete unanimity between himself and that gentleman.

Physical Features of the Region.

The region treated of may be described as extending from the international boundary northward to Bow river, or in latitude from 49° to 51° 20′. The eastern edge of the Rocky mountains proper (Laramide range) is defined by the line separating the Paleozoic rocks from those of the Cretaceous and Laramie, and, although this line is not a perfectly definite one, it corresponds closely with the orographic features, and the eastern front of the mountains is often particularly abrupt and striking. The want of definiteness referred to arises from the fact that embayments

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* Report on the Geology of the Bow and Belly Rivers region. Geol. Survey of Canada, 1882–'84.

and infolds of Cretaceous rocks occur in this part of the mountains, while at least one isolated area of Paleozoic rocks is found to the east of the main margin of the range. Both the mountains and the adjacent foothills have been subjected to similar parallel folding and disturbance at the same post-Cretaceous orogenic period.*

FIGURE I.—*Southwestern Part of the District of Alberta.*

The foothill belt varies in width from 10 or 12 miles in its southern part to about 20 miles at the north, in the vicinity of Bow river. Fundamentally, the foothills represent a bordering zone of folded and contorted Cretaceous rocks, reduced by denudation to series of more or less nearly parallel ridges and valleys. The rivers and larger streams from the mountains generally cut across nearly at right angles in wide and relatively low transverse valleys, while the higher ridges and hills occasionally surpass 5,000 feet in elevation.

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* For some notes on this and on the Pliocene history of the region, see Am. Jour. Sci., June, 1895, p. 463.

On the east the boundary of the foothills proper coincides with that of the flexed strata, and is nearly always quite definite, the corrugations ceasing abruptly and being succeeded by a wide, low syncline, which is continuous between the latitudes above referred to, and is occupied by the remnants of a long elevated plateau—that of the Porcupine hills. This plateau is throughout composed chiefly of sandstones of Upper Laramie age, but the Porcupine hills proper extend only from Oldman river northward to Highwood river, a length of about 60 miles, with an average width of some 20 miles. Further north they are represented by a series of detached, lower plateau areas, which continue to border the foothills on the east, while to the south of the Oldman the same syncline is also occupied by plateaus, but still less prominent and lower. Of the Porcupine hills proper, the highest part extends northward from the Oldman for about 40 miles, and here a few points reach 5,300 to 5,400 or even 5,500 feet, while considerable areas of ridges and broken plateau exceed 4,500 feet.

From the southern end of this high region, overlooking Oldman valley, the view is open to the base of the Rocky mountains, no comparable elevations of any extent existing in this part of the foothills. In the arc from west to southwest the mountains are distinct from 20 to 25 miles, but from the last bearing, around to south, the line of the mountains recedes rapidly, being more than 40 miles distant where it crosses the forty-ninth parallel. From south to southeast the lower continuing plateaus already mentioned are overlooked, but from southeast around to north the outlook is across the sea-like expanse of the Great plains, of which the rare, low, plateau-like elevations are scarcely distinguishable.

A profile drawn across any part of the country above described would show on the west the rugged front of the mountains (7,000 feet or more), next the much lower but irregular foothills, then a well marked depression separating these from the Porcupine hills, then the plateau of the Porcupine hills, and lastly the long eastward or northeastward slope of the Great plains; but a profile traced along the valley of any one of the larger streams, and thus following the actual drainage level of the country, would show a nearly uniform descent from the base of the mountains, only slightly increased in slope while crossing the foothill belt. These streams leave the mountains at an average elevation of about 4,350 feet. Along the eastern edge of the Porcupine syncline the plains have a nearly uniform height of about 3,300 feet, with which the general level of the rivers may be considered as practically coincident, although these often occupy postglacial valleys of from 100 to 200 feet in depth below the adjacent plain; thence to the northeastward the surface of the plain (with its rivers) gradually descends some 1,000 feet in a distance of about 120 miles.

The two most notable breaks in the continuity of the foothill belt and the Porcupine Hills plateau are those of the Bow valley and the valley occupied by the Oldman and its tributaries. The latter especially, which is not merely a wide river valley, but occurs in conjunction with the breaking off to the south of the highlands of the Porcupine hills, is an important and wide opening in the approaches to the mountains, and may be regarded as an irregular southwestern embayment of the plains, in which Laurentian erratics had already been found at an elevation of 5,280 feet above sealevel and upon the very margin of the mountains themselves. It was therefore chiefly in this region and in that of the Bow valley, taken in conjunction with the elevated tracts in their vicinity, that further information respecting the conditions of glaciation and the character of the western edge of the Laurentian drift seemed likely to be obtained. The southern high portion of the Porcupine hills in particular, it appeared, might be of peculiar importance in relation to such questions, for here it was probable that either moraines or terraces might characterize the farthest and highest limits of the drift of eastern origin.

SUMMARY OF PREVIOUS OBSERVATIONS.

Before stating the results of the late investigation it will, however, be useful to give, in the form of a summary, the facts connected with the superficial deposits previously recorded in the report of 1882–'84.

In the region of the Great plains of southern Alberta, to the east of the Porcupine hills and their representatives, an approximate estimate of the drift deposits as a whole makes these to average about 100 feet in thickness. In a few places on the line of section afforded by the Belly river all the recognized members of these deposits are together present, but in others only two or three of them are seen at a single locality. A complete section shows in descending order the following succession:

1. Stratified sands, gravels or silts.
2. Upper boulder-clay.
3. Stratified interglacial deposits, sometimes including lignite.
4. Lower boulder-clay.
5. Quartzite shingle, sometimes with stratified sands and silts.

The absolute and relative thickness of each of these deposits varies much, and along Bow river, somewhat farther to the north, the interglacial beds were not noted, and no line of separation as between an upper and lower boulder-clay was in consequence determined.* The under-

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*This may, however, in part result from the fact that the importance of such a separation was not recognized at the time these sections were examined, but it is certain that there is here no such striking plane of division as on Belly river. Still further north, on Rosebud creek, Mr J. B. Tyrrell again found two boulder-clays separated by a thin layer of lignite. Geol. Survey of Canada' vol. ii, new series, p. 143 E.

lying "quartzite shingle," subsequently named by Mr McConnell the "Saskatchewan gravels,"* was, however, seen in a number of places along the Bow, the evidence here, as elsewhere, being such as to show that this deposit, although widespread, is generally characteristic of the relatively lower tracts of the plains.

It is thus not often possible to determine, where boulder-clay is met with in isolated exposures, whether the lower or upper boulder-clay is represented, but it is probable that the upper or newest boulder-clay is that generally seen in all the more superficial excavations.

> "Overlying the boulder-clay are widespread stratified deposits, the distribution of which assists materially in giving uniformity to the tracts of level plain. It is, indeed, quite exceptional to find the surface soil consisting of boulder-clay disintegrated in place, and this occurs only on the slopes of plateaus, or in hollows formed by denudation. That the beds overlying the boulder-clay have not been merely formed by its rearrangement in water without the addition of new material, is indicated by the fact that in many places erratics much larger than those characterizing the boulder-clay of the locality are found strewn over the surface of the country.† The beds observed in river sections and elsewhere to overlie the boulder-clay are generally gravels or sands below and sandy or clayey loams above. The latter form the subsoil over most of the region, and are generally rather pale brownish- or yellowish-gray in color."

Further study has served to verify and in some directions to amplify the statements summarized in the foregoing paragraphs.

On the subject of terraces and water-leveled tracts it is said in the same report:

> "Terraces are prominent features in some parts of the river valleys in this district, but are generally clearly due to the action of the river itself at a former period. The extensive tracts of almost perfectly level prairie which occur, afford evidence of water action of some duration and may be regarded as wide terraces."

The conditions of the drift deposits in the region of the Porcupine Hills were not fully examined at this time and it is merely stated in the report that—

> "The eastern face of the Porcupine hills appears from a distance to be very distinctly terraced, but this aspect was found to be due to the outcrop of the nearly horizontal sandstone beds."

Further and more extended investigation in 1894 shows that while the existence of these sandstone outcrops has contributed to the form assumed by the Porcupine hills, true water-formed terraces also exist and are actually found to extend to very great elevations, as more fully noticed in the sequel.

Respecting the general aspect of the drift deposits in the foothill re-

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† Or "South Saskatchewan gravels." Ann. Rep. Geol. Survey of Canada, vol. i, new series, p. 70 C.

‡ Compare McConnell. Op. cit., p. 74 C.

gion between the Porcupine hills and the base of the mountains, little change can be made in the following statement given in the report of 1882-'84:

> "Terraces in the entrance to the South Kootanie pass, at a height of 4,400 feet, have already been described in my Boundary Commission Report (1875). In the valleys of Mill and Pincher creeks, and those of the forks of the Oldman, east of the actual base of the mountains, wide terraces and terrace-flats are found, stretching out from the ridges of the foothills, and running up the valleys of the various streams. Actual gravelly beaches occasionally mark the junction of the terraces with the bounding slopes, and they have no connection with the present streams, which cut through them. The level varies in different localities, but the highest observed as well characterized attains an elevation of about 4,200 feet. In the Bow valley near Morley, and thence to the foot of the mountains, similar terraces are found, which are quite independent of the modern river; and in the wide valley of the Kananaskis pass a series of terraces was seen from a distance which must rise to an elevation of at least 4,500 feet."

It is important to note that in all this region there can be no doubt as to the origin of the crystalline erratics attributed to the Laurentian plateau of the east. Neither the Cretaceous nor Laramie rocks of the plains nor the Paleozoic strata of the mountains yield any such material, while the eastern derivation of the granitic and gneissic drift is further evidenced by its connected spread across the plains to the region of its supply. Thus the western limit of such characteristic erratics clearly indicates the extent of the drift from the Laurentian plateau. In regard to this western limit, it then was observed that it practically reaches the base of the Rocky mountains near the forty-ninth parallel, where Laurentian boulders were found at a height of 4,200 feet. Some 30 miles to the northwest and within a few miles of the mountains similar erratics were found at the mill on Mill creek (3,800 feet), and one was seen near Garnett's ranch (4,200 feet). It was added:

> "I did not, however, observe any Laurentian drift on the North fork of the Oldman, and it is probable that it is absent or nearly so in the district sheltered by the higher parts of the Porcupine hills. On the Bow river no Laurentian or Huronian erratics were seen west of Calgary, and even after their first appearance they were very scarce for some distance" (to the eastward). The elevation of the Bow at Calgary is 3,393.6 feet,* and in comparing this with that of the more southern localities the conclusion was drawn that "the western limit of the Laurentian drift cannot conform strictly to any contour line of the present surface of the country."

The later investigations tend somewhat to modify the above statements in showing that Laurentian drift does occur in a scanty and

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*This and some other elevations given here are derived from the results of the irrigation survey or from railway surveys. Most of the heights are less precise, depending on barometric observations reduced by comparison with Calgary. All may, however, be accepted within maximum limits of error (±) of 20 feet, and are sufficiently exact for all purposes of the present paper.

sporadic manner behind the Porcupine hills, and also by the discovery of such erratics on hills of some height above the Bow river at Calgary, although that place still remains the western limit in so far as the valley of the Bow is concerned.

The elevations just mentioned were not, however, the highest at which Laurentian erratics were found previous to the publication of the report of 1882–'84, for—

> "In 1883 several indubitable Laurentian boulders, representing three varieties of granitic and gneissic rocks, were found about 20 miles north of the forty-ninth parallel, at an elevation of 5,280 feet."

These boulders occur stranded upon a morainic ridge, due to local glaciers of the adjacent mountains. On a plateau to the south of the Porcupine hills Laurentian stones were found, though not abundantly, at a height of 4,390 feet, while similar erratics were observed to be scattered over the high country near Milk river at a distance of from 30 to 40 miles from the mountains and at an elevation of 4,200 feet. The observations since made in the Porcupine hills enable considerable additions to be made to our previous knowledge of the maximum height attained by such eastern drift near the Rocky mountains.

Digressing for a moment to places farther from the eastern base of the mountains, it will be useful to remember that on West butte of the Sweet Grass hills, 90 miles east of the mountains,* Laurentian fragments were found to a height of 4,660 feet, while according to Mr McConnell the drift of this origin finds its limiting height on the Cypress hills 200 miles from the mountains, at 4,400 feet.† Both the places last mentioned are not far from the forty-ninth parallel; but much farther to the north, in the Hand hills (latitude 51° 25′, longitude 112° 20′), Mr J. B. Tyrrell has found a similar upper limit for Laurentian boulders at 3,400 feet.‡ These observations are cited here for purposes of comparison.

In the report of 1882–'84 it was stated that a similar limit occurred on the Rocky Spring ridge of northern Montana, 10 miles south of the boundary line and 66 miles from the mountains, at 4,100 feet. The plateau only slightly exceeds this height, and, while convinced of the accuracy of the observation at the time, its wide discrepancy from other results may perhaps be regarded as leaving it open to suspicion. I have not had an opportunity since of verifying it.

Before dealing with the facts ascertained in 1894, it should be noted that Mr McConnell had in 1890 carefully examined the sections of the glacial deposits along Bow river between the mountains and Gleichen (about 80

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* In this and other cases, unless otherwise noted, distances from the mountains are measured at right angles from the nearest part of the base of the range.

† Op. cit., p. 75 C.

‡ Annual Report, Geol. Survey of Canada, vol. ii (n. s.), p. 145 E.

miles eastward), and there found reason to believe that the Saskatchewan gravels of the plains represent and gradually pass into a "western boulder-clay" in approaching the mountains. This observation has remained unpublished, but now appears to be well established, and it follows from it, taken in connection with the facts already summarized, that there are no less than three distinct boulder-clays in the region here treated of, the oldest or "western" boulder-clay being followed in time by that previously named the "lower" boulder-clay, which is in turn distinctly separated from the "upper" boulder-clay over a considerable part of the district, at least, by interglacial deposits. The western boulder-clay, as its name implies, contains no Laurentian or Huronian material, while such material, as well as limestone derived from the Winnipeg basin, is present in both the others. This general statement will serve as a clue to many of the observations subsequently detailed.

In further presenting the results of recent observations attention will first be given to the sections found on the Belly and Oldman rivers, to the surface of the plains in their vicinity, and to the wide low area which is occupied by the tributaries of the Oldman in the neighborhood of the mountains.

SECTIONS IN THE VALLEYS OF OLDMAN AND BELLY RIVERS.

Although in the report of 1882–'84 the occurrence of two boulder-clays with an interglacial deposit was noted at Coal Banks (now Lethbridge) and a photograph was reproduced showing these deposits there running for miles along the bluffs of the river valley, no detailed section was recorded for this place. A careful examination was made of this section in 1894, at a place about four miles north of Lethbridge, with the following result: The valley of the river at this place is cut down about 300 feet into the prairie. From 50 to 80 feet above the water level is occupied by dark shales of the Pierre formation of the Cretaceous, resting upon which, along a perfectly even line, are the Saskatchewan gravels or "quartzite drift," with a thickness from 10 to 15 feet. The upper part of the shales, to a depth of two feet, is weathered and brownish in color. The gravels are coarse, often containing stones up to six inches in diameter, all well smoothed and water-worn, but often not perfectly rounded. They are generally arranged in a rather tumultuous manner; that is, not in regular layers graded according to size, and with the pebbles sometimes standing on end. The interspaces are filled with a coarse gray sand, and a similar material forms occasional discontinuous layers a few inches or feet in thickness on the upper surface of the gravels. The stones are chiefly characteristic Rocky Mountain quartzites, but a considerable number of pebbles of limestone from the same source are included, as well as a few examples of the peculiar Rocky Mountain "greenstone," about which some remarks are made subsequently. One or two pebbles of peculiar crystalline rocks, not Laurentian, and probably from intrusive masses in the mountains, were also found.

The Saskatchewan gravels are sharply cut off above by a dark boulder-clay, the color of which is evidently due to the incorporation of a considerable proportion of the material of the Pierre shales and in which rather numerous crumbs of the coal of the vicinity are contained. The included stones are varied in origin, embracing quartzites from the mountains, Laurentian gneisses and some limestone of mountain origin, all often distinctly striated and glaciated. The thickness of this boulder-clay is about 50 feet.

Next in ascending order is a thickness, from 25 to 30 feet, of pale colored silty beds. often very finely stratified and in certain layers assuming a "leathery" character and showing layers of almost paper-like fineness. Crumbs of coal are present, but no lignite or peaty layer is here seen. This well bedded intercalation preserves its place and character for miles along the valley and is continuous with that previously described lower down the river.*

Overlying the last is the "upper" boulder-clay, yellowish gray in color, and this, so far as can be ascertained, extends nearly or quite to the top of the bank or the general level of the adjacent prairie. Stones and boulders are not notably abundant in it at this place, but those which occur came both from the mountains on the west and the Laurentian plateau on the east.

Summarizing this section and placing it in relation to others described in the report of 1882–'84, we obtain the following representation of the drift deposits of this part of the plains, the section on the right being that farthest from the base of the mountains:

Sections on Belly River.

Near Lethbridge.		Driftwood bend.		Wolf island.	
Distance from mountains, 60 miles.		Distance from mountains, 75 miles.		Distance from mountains, 85 miles.	
Height of base of section, 2,655 feet.		Height of base of section (approximate), 2,360 feet.		Height of base of section (approximate), 2,270 feet.	
	Feet.		*Feet.*		*Feet.*
Upper boulder-clay (about)..	140	....	40	....	100
Interglacial deposits..........	30	(Sands, ironstone, carbonaceous layers).................	33	(Sandy clay, with lignite)...	8
Lower boulder-clay............	50	....	80	....	15
Saskatchewan gravels........	15	(Below river level.)		(Gravels, sands and clay)....	40
Pierre (Cretaceous) shales..	65			(Cretaceous rocks).......	10
	300		153		173

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* Report of Progress, Geol. Survey of Canada, 1882–'84, p. 144 C.

Before continuing the notes made in the deeper river sections to the westward of Lethbridge, a few words may be devoted to the character of the general surface of the plain corresponding to the sections above cited. This is well shown in numerous fresh cuttings along the line of railway between Dunmore (near Medicine Hat) and Lethbridge, a distance from east to west of 100 miles. Whether in the rolling prairie toward the east or the nearly level prairie to the west, the surface is almost uniformly composed of gray or brownish gray silty or loamy material, of which the depth may be stated to vary from two to five feet, although certainly greater in some places. On the crests of knolls and ridges and in some of the valleys which have evidently been cut out by postglacial flows of water, this deposit has been removed, leaving a grayish boulder-clay, which sometimes contains large stones at the surface. The stones are generally Laurentian, but are seldom abundant. It might be supposed that the prolonged action of rains or that even of the winds would in time produce a surface deposit of this kind, but much of the plain is so entirely flat that such explanations appear improbable. Neither are the projecting ridges notably bouldery, as should be the case if much denudation of their finer material had occurred, and the circumstances favor a belief that the silty deposits have been laid down in a body of rather shallow water, coextensive with the plain itself, in which some slight rearrangement of the exposed parts of the boulder-clay has taken place. There is some appearance of rolled gravelly deposits about the slopes of the ridges, but the cuttings are insufficient to show these fully.

Following the axis of the main depression already alluded to, no exposures have been found further to the westward in which the lower and an upper boulder-clay are clearly distinguished, and as the sections are not continuous, it becomes impossible to decide in each case which is represented. In an exposure nearly opposite Rye Grass flat, 12 miles west of Lethbridge (52 miles from the base of the mountains), locally upturned Laramie beds are overlain by 10 feet of stratified sand and silt, followed by 20 feet of boulder-clay, which again is followed by 12 feet of rolled gravels, apparently replaced in a short distance horizontally by stratified sands. The whole section is capped by some feet of the loamy superficial silts above described. The boulder-clay seen in this section includes a number of discontinuous layers of sand and gravel.

Another section of considerable length two miles and a half below Macleod (45 miles from the base of the mountains, elevation 3,024 feet) was carefully examined by Mr McConnell, and is described by him as follows:

" The boulder-clay is here 45 feet in thickness from the river level and is overlain by 20 feet of sands and silts which contain layers of finely foliated leathery clays. The lower part of the boulder-clay is darker in color than the upper, but there is no division into upper and lower members, as dark and light layers alternate and change in color when followed along the bank. Stones both of western and eastern origin occur throughout, the former preponderating toward the bottom and the latter toward the top. The mass of the boulder-clay is in some places hard and clayey, in others soft and sandy, that of the last mentioned character passing occasionally into layers of sand and gravel."

The stratified sands, silts and leathery clays or shales of the above section much resemble the interglacial beds of Lethbridge, but, as already stated, there is here no means of certainly identifying the boulder-clay.

Farther up along Oldman river, at the mouth of Beaver creek (28 miles from the mountains, elevation about 3,260 feet), a bank examined by Mr McConnell shows, above the river level, "50 feet of compact boulder-clay overlain by 6 feet of stratified silts and sands. There is here a marked diminution in the proportion of eastern drift as compared with the last section, a rough estimate making it about two per cent of the whole."

In the same vicinity, on Oleson creek, about 400 feet above the river and to the north of it, a moderately indurated pale drab silty or sandy boulder-clay was found holding comparatively few stones, but some of them distinctly glaciated.

Still further to the westward, at the confluence of the North and Middle forks of the Oldman (about 15 miles from the line of the base of the mountains, elevation approximately 3,650 feet), a good section was found, which may be set out as follows in descending order:

	Feet
1. Well rolled and rounded gravels, with some stones as much as 8 or 10 inches in diameter, apparently all of Rocky mountain origin	10
2. Good typical boulder-clay, moderately indurated; matrix brownish yellow and earthy, containing glaciated stones and boulders of moderate size, mostly subangular, but some well rounded, derived from the mountains or from the Cretaceous rocks of the foothills, but chiefly quartzites; some limestone and a few examples of greenstone. Two or three small pieces of Laurentian rocks were found which probably came from this boulder-clay	20
3. Stratified, earthy, brownish yellow sands, containing a few glaciated stones.	10
4. Obscurely stratified gravels, containing some stones 10 inches through, all well rounded and like beach or river shingle. Traces of glaciation were suspected on a few of these, but were in no case observed to be absolutely decisive. The line between this and the overlying deposit is quite regular and definite. Although there is an appearance of blending in a thickness of a few inches, there is no sign of any intervening condition of importance	10
5. Laramie sandstones and shales to river level	40
	90

Numbers 3 and 4 of this section are believed to represent the Saskatchewan gravels, while number 2 may be either the lower or upper boulder-clay of the plains. Less than a mile to the northward the boulder-clay was observed to rest directly upon the Laramie rocks, numbers 3 and 4 having run out. Number 4 has in some places a clayey matrix, thus beginning to assume the character of the "western" boulder-clay.

About two miles further north, along the North fork and well behind the southern part of the Porcupine hills (elevation about 3,900 feet), another section was examined, of which, however, the total thickness remained indetermined because of slides in the bank. This again shows boulder-clay of a somewhat earthy and soft character, but containing many stones, derived from the mountains or adjacent foothills. The limestone pebbles are often distinctly but very lightly striated, and have apparently been well rounded by ordinary water action before the striation had been added. Two small crumbs of Laurentian material were discovered by search on the face of this exposure, but the decrease in importance of such material in the boulder-clay to the westward and where sheltered by the high ridges of the Porcupines is very apparent.

The comparatively soft and earthy character of the boulder-clay seen behind the Porcupine hills was generally observable.

Reverting to the main line of approach which we have been following toward the mountains, an exposure on the South fork of the Oldman, examined in 1883, may next be alluded to. This is distant from the mountains about 12 miles, with an approximate elevation of 3,700 feet. It again shows a boulder-clay, similar to the last, overlying a few feet of gravel derived from the mountains. Both deposits occupy a hollow, possibly that of an old river valley, as shown in the diagram annexed.

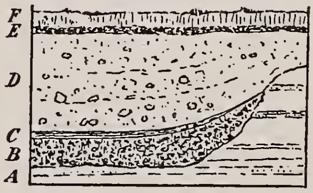

FIGURE 2.—*Section on the South Fork of Oldman River.*

A = Laramie (Willow creek) beds.
B = Saskatchewan gravels.
C = finely stratified clays.
D = boulder-clay.
E = surface gravel.
F = soil.

Base of section 25 feet above present river-level.

In 1881 another section was noted on Mill creek, still nearer to the mountains (six miles distant, elevation 3,817 feet), which showed boulder-clay of the usual character underlain by a very hard boulder-clay or till of different aspect, below which was a few feet in thickness of fine, compacted gravels. Some Laurentian stones were found on the surface in this vicinity above the level of the section, but none were seen in it. A similar instance of bouldery clay overlying thin layers of gravel was discovered in the same year high up on Pincher creek, in this neighborhood, within a couple of miles of the actual base of the mountains.

The two last mentioned localities are within the limit of the country characterized by moraines, evidently due to local glaciers from the Rocky mountains, and the indurated boulder-clay of the Mill Creek section is believed, like the moraines, to be a deposit of these glaciers. The lower gravels in this case and in that of Pincher creek are obviously due to preglacial streams flowing from the mountains, and, although the name Saskatchewan gravels may be applied to them, they here evidently antedate the eastern gravelly representative of the Rocky mountains or earliest boulder-clay. Further to the east, where this boulder-clay gradually passes into such gravels, there is no means of distinguishing between wholly preglacial beds and those which may have been formed during the main period of the Rocky Mountain glaciers. Many exposures of the Saskatchewan gravels may include both, and this without necessitating the supposition of any great chronologic break.

Southern Part of the Porcupine Hills.

Having thus followed the main southern line of approach at low levels to the mountains, attention may next be given to the southern end of the Porcupine hills, which overlooks this avenue on the north side, at a distance from about 15 to 30 miles from the base of the mountains. Oleson and Beaver creeks flow southward from this end of the hills, and it was chiefly in the vicinity of these streams that the observations noted were made.

In traveling westward from Macleod (situated on the plains at an elevation of 3,070 feet) to Oleson creek by the regular trail north of Oldman river, a distance of 14 miles, a gradual ascent is made which becomes greater as the flanks of the hills are reached. The following terrace-levels were noted on this route:

North of Macleod an extensive gravel plain forming the angle between Oldman and Willow rivers is reached. This rises gradually from 3,130 feet in a distance of a couple of miles to 3.220 feet. Its surface is not absolutely flat, but is diversified by low swells or ridges, which generally trend north and south.

This plain is bounded to the west by a distinct rise leading to another similar plain or wide terrace, also gravelly, of which the eastern part is at a height of 3,275 feet, and which continues to slope up gradually to the westward. The gravels of this plain and the last are composed chiefly, but not entirely, of well rolled Rocky Mountain quartzites. At 3,286 feet on this second plain is found running northward a line of remarkable large boulders,* composed of quartzite or conglomerate. These are identical

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* These remarkable boulders are in size and composition unlike any observed in the boulder-clays. They have undoubtedly been water-borne and may probably have been derived from some particular region of the Laurentian plateau which became tributary at a later stage of the Glacial period.

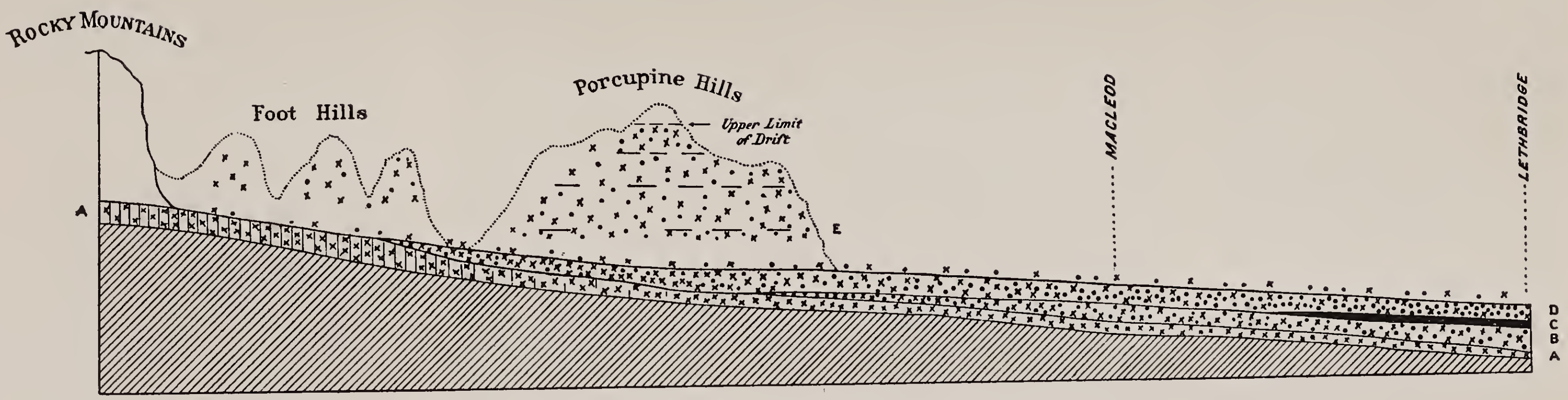

FIGURE 3.—*Diagrammatic Section from Lethbridge to Base of Rocky Mountains, along the Valley of Oldman River.*

A = (Albertan stage): Western boulder-clay passing to the eastward into Saskatchewan gravels.
B = "lower" boulder-clay.
C = interglacial deposits.
D = "upper" boulder-clay.
E = terraces and drift on the Porcupine hills.

This diagram is based on the hypothesis that the upper boulder-clay of the plains is that extending farthest to the west. Crosses indicate drift material from the mountains; dots, drift material from the Laurentian plateau. The Porcupine hills and foothills to the north of the section are shown in broken lines. The vertical scale is very greatly and not uniformly exaggerated.

in character with those noted in the report of 1882–'84 as occurring near the lower part of Waterton river at a height of between 3,200 and 3,300 feet,* and it may be added here that boulders of the same kind were found by Mr McConnell on the northern part of the Porcupine hills at a height of 3,950 feet, and on the Nose hills near Calgary at 3,940 feet.

At 3,316 feet is a boulder-strewn terrace with some pretty large boulders, both of Rocky mountain and Laurentian origin; at 3,387 feet, another terrace similarly characterized; at 3,532 feet, a terrace with rolled gravel on the surface and an abundance of eastern drift, and again at 3,643 feet occurs still another well marked and wide terrace with similar mixed drift.

From this a descent was made to our camp on Oleson creek (3,600 feet) and from this place, in the course of a rather long excursion in the hills to the northward, the following terrace-levels at greater altitudes were observed. These are briefly enumerated below, but it must be understood that many more such levels might have been noted had further time been given to the investigation. Possibly, at a distance of some miles, a quite different series of water-levels would have been recognized, for it appears probable that almost every stage in a gradual descent of the water-line may be found to be marked in some part of the Porcupine hills.

3,853 feet, a terrace-like flat with rolled quartzite and Laurentian gravel.
3,877 feet, an evident terrace with similar gravels, including some Rocky mountain limestone.
3,898 feet, a faintly impressed terrace with similar gravels.
4,182 feet, approximately, a terrace with similar gravels.
4,281 feet, a terrace with similar gravels.
4,349 feet, a terrace with similar gravels, many large well rounded stones, and a considerable proportion of limestone referable to the Winnipeg basin.
4,505 feet, a flat-topped hill, the highest in this vicinity, and evidently marking a terrace-level, covered with similar well rolled gravels, including Rocky Mountain quartzites and limestone, as well as Laurentian gneisses and Winnipeg limestones.

It is thus evident that from the level of Macleod to the highest point above noted there is an uninterrupted series of terraces, covered with well rounded pebbles of mixed eastern and western origin. The erratics of eastern origin are not less abundant at higher than at lower levels, and while some of the Rocky Mountain stones are of considerable size, the gneissic Laurentian boulders are, on the whole, larger at high levels, being often as much as three feet in diameter, while some large pieces of Winnipeg limestone were also seen at the highest levels. No glaciated stones were observed on these higher terraces, nor any signs of glaciation on the

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* Op. cit. 14 pp. 8, C, 149 C.

sandstone outcrops where these occur, but the rock in place is rather too soft to preserve such traces well had they existed upon it. The peculiar greenstone of the Rocky mountains before referred to is not infrequent at all levels, and as this particular rock occurs in place in the mountains (as an interbedded layer) scarcely as far north as latitude 49° 30′, it must have traveled in a northeastward direction in order to reach this part of the Porcupine hills. The matrix of the gravels, wherever seen, is a whitish silty or sandy material, perhaps in part composed of disintegrated sandstones of local origin, but including grains of similar composition to the pebbles themselves.

The flat outlines of the hills in all this southeastern part of the Porcupines appears to be in the main plainly due to water-levelling, although assisted by the practically horizontal attitude of the sandstone beds. From the highest point here reached the terracing of the hills may be finely seen for many miles to the northward, but still higher and partly wooded ridges to the westward showed toward their summits an altogether different and rougher character, although fundamentally composed of the same Laramie rocks. The highest terrace seen on the hills, near the headwaters of Beaver creek, was very well marked, and was estimated by eye from a distance to reach about 4,900 feet above sealevel.

In continuing the inquiry it became evidently necessary to examine the higher ridges above alluded to, and this was accomplished from the upper valley of Beaver creek, whence an ascent was made to the highest point in that vicinity, locally known as Five-mile butte. In this region the total amount of foreign drift is less considerable and distinct terraces are seldom observable, facts doubtless due to the shelter afforded by adjacent highlands on all sides, but particularly to that of the wide belt of hills and ridges to the eastward. Our camp on Beaver creek was at an elevation of 4,222 feet, and in ascending from it to Five-mile butte, on the east side of the valley, the following notes were made:

4,950 feet, a few well rolled pieces of Laurentian, Winnipeg limestone and Rocky Mountain quartzites.

5,070 feet, a few small Laurentian pebbles.

5,144 feet, Laurentian boulders 2 feet 6 inches through, Rocky Mountain limestone, quartzite drift and probably a little Winnipeg limestone.

5,250 feet, a projecting point on the high ridge showing abundance of well rounded Laurentian and quartzite drift.

At 5,300 feet the ridge becomes flat-topped and probably marks a terrace-level. It is strewn with numerous well rolled pebbles of eastern and western origin, including Laurentian, Winnipeg limestone, and Rocky Mountain limestone and quartzite. Some of the Laurentian boulders are 2 feet in diameter.

Above this level nothing but debris of local sandstones was found, the highest point of Five-mile butte being reached at 5,365 feet.

It will be noted that the Laurentian drift is in this neighborhood markedly more abundant at the higher levels, the upper limit of the traveled material standing above all the hills and ridges to the eastward. A distinct terrace was observed on the opposite (west) side of Beaver Creek valley at an estimated height of about 5,130 feet. This may possibly correspond with that previously noted as seen from the hills above Oleson creek, but is not the same. The levels in both cases are necessarily somewhat uncertain.

In crossing the last ridge of the Porcupines on the west, between Beaver creek and the North fork of Oldman river, a height of 4,986 feet was reached, and here a few pebbles of Rocky mountain origin were found, although on projecting points 200 feet higher no traveled drift was observed. This evidence is, however, of a purely negative character. On the west slope, in descending toward the North fork, Laurentian drift was first recognized at 4,710 feet and continued sparingly down to about 4,060 feet. None was seen near the river itself (3,960 feet).

Plain and Valley West of the Porcupine Hills.

Between the Porcupines and the foothills proper a plain some miles in width here runs north and south. This to the eye appears almost perfectly level. It is continued southward beyond the Middle and South forks of the Oldman with increasing width and probably with a somewhat decreasing elevation. The lowest part of this plain actually traversed on our route is near the confluence of the North and Middle forks, with an elevation of 3,750 feet. In about three miles farther north it rises gradually to 4,140 feet, the surface being generally gravelly (number 1 of section on page 42). This gravel plain resembles in character that occurring near Macleod at an elevation lower by about 1,000 feet, but no eastern drift was found among the pebbles, which appear to have been entirely brought down by rivers flowing from the mountains.

In following the plain northward it becomes narrowed, but again widens about the bend of the North fork, where its average elevation is about 4,200 feet. From this vicinity (near the Upper Walrond ranch) the wide valley of North fork runs northwestward to the base of the mountains. It is floored by a regular terrace, apparently in continuation of the plain last referred to, which attaches to the bases of the neighboring hills some miles to the west at an elevation of about 4,400 feet.

From the Upper Walrond ranch a continuous valley, bounding the Porcupine hills on the west, runs northward to Highwood river, a distance of 48 miles. A very few small Laurentian boulders were seen near the ranch, and one was observed about a mile and a half to the north at a

FIGURE 1.—BLUFF ON HIGHWOOD RIVER.

Showing two boulder-clays, the higher passing above into stratified silts. The base of the boulder-clay here rests directly on Laramie rocks.

FIGURE 2.—PART OF SECTION ON BOW RIVER NEAR CALGARY.

Showing clayey Saskatchewan gravels overlain by boulder-clay.

BOULDER-CLAYS AND SASKATCHEWAN GRAVELS.

height of 4,400 feet; but no more eastern drift of any kind was found along the valley for 30 miles northward. If not entirely absent, it must here be extremely scarce.

At the distance just noted, near the chain of small lakes between the North branch of Willow creek and the South branch of the Highwood, where the wide gap of the Highwood valley begins to lay the country traversed more open to the eastward, a single Laurentian boulder was again seen. This was opposite the third or northernmost lake, at an elevation of 4,406 feet.

In this vicinity a well marked terrace was also found at 4,270 feet, with several others faintly impressed on the hillsides up to 4,500 feet, but no higher. The upward limit of terracing and of thick drift deposits appears here to be well defined. Large fragments of Rocky Mountain limestone are found here and there throughout this part of the foothills generally stranded on prominent ridges of sandstone.

At the head of the South branch of the Highwood, brownish earthy boulder-clay, with stones wholly derived from the mountains, was seen in the bank of a stream apparently resting directly on bed-rock. The surface of this boulder-clay forms a wide terrace-level in which the stream valley is cut out, with an elevation of 4,240 feet, rising to about 4,290 feet where it meets the slopes of the hills. In following the South branch northward to a point six miles from its confluence with the main Highwood, at a height of 3,960 feet, boulder-clay like the last was again seen, but here holding a few very small Laurentian fragments.

Highwood River and Vicinity.

To the eastward of the South branch Mr McConnell made a long detour among the northern ridges and plateaus of the Porcupine hills, the highest of which are there about 4,740 feet. Upon these he found abundance of Rocky Mountain limestone and quartzite, but no eastern drift above 4,150 feet and very little drift of this origin anywhere.

In the bank of the main Highwood, four miles above the mouth of the South fork (13 miles from the base of the mountains, elevation about 3,700 feet), Mr McConnell examined a section showing 35 feet of boulder-clay overlain by a considerable thickness of silts, and these in turn capped by river gravels. The boulder-clay is dark brownish below and light yellowish above, with stones seldom exceeding six inches in diameter, which, so far as observed, are wholly of western origin.

From the mouth of the South branch the Highwood was followed down to the crossing of the railway, and midway between these points some fine sections were found (see plate 1). The height of the river is here about 3,500 feet and the distance from the mountains 19 or 20 miles. In descending order, the bluffs here show—

	Feet
1. Well stratified and current-bedded silts	5
2. Pale yellowish gray boulder-clay	15
3. Dark gray boulder-clay	20
4. Laramie sandstones and shales	15
	55

Both parts of the boulder-clay hold many and some large stones, often well glaciated and apparently all of western origin. The line between the two layers of boulder-clay is horizontal and quite distinct. Many of the larger stones occur about this level, and one of them was seen to lie about half in the lower and half in the upper division. It is not certainly known that the division between two classes of boulder-clay found in this and the preceding section corresponds with the horizon of the interglacial deposits previously described, but it is believed that numbers 1 and 2 correspond with numbers 2 and 3 of the Calgary section (see page 53).

A very few Laurentian fragments were seen in traveling from this place eastward to the town of High River, at the railway crossing (3,371 feet). They appeared to be more abundant to the east.

Highwood River to Calgary.

From the town of High River the regular road was followed northward to Calgary, 33 miles, crossing Sheep, Pine and Fish creeks and rising over eastward projections of the lower plateau, which here represents the Porcupine hills. The highest point reached between Highwood river and Sheep creek is about 3,623 feet. Here less than one-hundredth of the drift stones are Laurentian, the rest being from the mountains. At 3,495 feet, on the northern descent toward Sheep creek, perhaps one-fiftieth of the stones are Laurentian, but at a corresponding elevation on the southern slope toward the Highwood such stones are exceedingly scarce. At the crossing of Sheep creek (about 3,400 feet) a partially stratified stony deposit, resembling boulder-clay but showing no striated stones, contains a considerable proportion of Laurentian fragments.

Between Sheep and Pine creeks, beginning to the south at about 3,600 feet, rising to 3,790 feet and falling again toward Pine creek to 3,500 feet, is a lumpy, undulating country, comprising some hollows and swampy depressions without outlet, and repeating somewhat the characters of the Missouri Côteau on a much reduced scale. The surface is pretty thickly covered with soil, which is seen in places to be underlain by deposits of rolled gravel, but no sections of any depth occur. The extent of this country where crossed is about six miles. It is the only tract met with in this entire region which in any degree simulates the characters usually assumed as morainic. Nearly all the stones are from the west, but a very few Laurentian boulders are seen.

At the north end of the railway bridge over Fish creek a cutting has been made in pale grayish yellow boulder-clay, in which most of the stones are well rounded (though some pieces of Rocky Mountain limestone are striated) and all are of western origin. Laurentian boulders are here, however, not uncommon on the surface at elevations of 3,400 to 3,500 feet.

The higher parts of a wide plain, through the center of which the Bow valley is trenched, in the vicinity of Pine creek, have a level of about 3,500 feet.

Between Fish creek and Calgary, at heights of 3,400 to 3,500 feet, Laurentian boulders are found in increasing numbers. Some of them are several feet in diameter, and they are scattered over the surface apparently in association with deposits overlying the boulder-clay.

Sections in Bow River Valley.

At Calgary we reach Bow river, which has in the introductory pages of this paper been described as the second great avenue of approach to the mountains at low levels and the northernmost in the region here considered. Following the plan already adopted in the case of the Belly and Oldman rivers, some notice will now be given of observations made along the Bow from east to west, or in order, ascending the stream toward the mountains. These observations are chiefly those of Mr McConnell, who in 1890 descended the river in a boat from Morley to the Blackfoot crossing with the special purpose of investigating the superficial deposits, and supplemented this by a critical examination of these deposits at Medicine Hat. Medicine Hat is situated at a distance of about 155 miles from the nearest part of the mountains and about 270 miles from the mountains by a line measured along the general course of the Bow and South Saskatchewan rivers. Mr McConnell writes:

"The glacial deposits at Medicine Hat consist of light colored compact boulder-clays of the ordinary type, but showing in places faint lines of stratification, overlain by stratified sands and underlain by beds of quartzite pebbles, occasionally cemented into a conglomerate and sometimes associated with sands and silts.

"The line between the material derived from the east and that coming from the west is here drawn at the base of the boulder-clay; above that horizon eastern gneissic and limestone boulders and pebbles, the latter often striated, are common, but no rocks of undoubted western origin were observed. The beds of well rounded quartzite pebbles below the boulder-clay, on the other hand, are derived, so far as known, entirely from the west, although they may here in part represent redistributed Miocene conglomerates like those of the Cypress hills, which were brought down from the mountains in Miocene times.

" Twenty miles above the Blackfoot crossing or 175 miles above Medicine Hat, where the next section was examined, the conditions have entirely changed. At this particular place the underlying gravels are absent and the boulder-clay holds both eastern and western drift intimately commingled throughout, pebbles of unmistakable Laurentian gneisses and well characterized Rocky Mountain limestones often lying side by side in the same hand specimen. The relative proportions of the two drifts at this point, 100 miles east of the mountains, measuring along the valley of the Bow, are nearly equal. In descending the river western drift of a recognizable character gives out in the boulder-clay before Medicine Hat is reached, and in ascending it the eastern drift gradually diminishes in relative quantity and disappears altogether above Calgary, 40 miles east of the mountains, or about 50 miles if the Bow valley be followed.

" Twenty-five miles above the Blackfoot crossing a boulder-clay section 110 feet in thickness is exposed. The boulder-clay is here separated into an upper and lower division by a band of stratified sands, the lower boulder-clay being darker colored than the upper one and differing from it also in containing a larger proportion of western drift. The junction between the two boulder-clays is not straight, but follows an irregular wavy line.

"At Pine canyon, eight miles above the last section, the Laramie sandstones are overlain by the Saskatchewan gravels 10 feet thick, above which is a peculiar morainic-looking deposit 40 feet thick, consisting of angular blocks of Laramie sandstone of local origin, gneisses and limestones from the east and limestones and quartzites from the west, all mixed confusedly together in a matrix of coarse sand and clay.

" Four miles above the last exposure the boulder-clay, here 50 feet thick, rests directly on the older rocks. The ratio of eastern to western drift in this exposure was estimated at about 1 or 2. A notable feature of the section is the presence in it of a gneissic boulder of eastern origin measuring fully three feet in diameter. The ordinary size of the eastern pebbles in the boulder-clay along this portion of the river seldom exceeds three inches in diameter.

" Two miles above the mouth of Highwood river the Saskatchewan gravels appear again. They consist mostly of rounded quartzite pebbles and boulders, ranging in size from one to twelve inches in diameter, and have a thickness of eight feet. The pebbles increase in size toward the base of the formation. The boulder-clay above the gravel holds occasional gneissic pebbles, but they are small and scarce.

"Two miles above the last exposure the pebble bed passes into dark clays filled with stones of western origin only. Above this is 170 feet of boulder-clay, alternating in places with sandy layers. A mile below the mouth of Fish creek the gravels reappear, but are replaced a mile above Fish creek by stratified sands. Two miles farther on the sands pass into gravels again, and these continue to underlie the boulder-clay as far as Calgary. West of Highwood river the western gravels underlying the boulder-clay consist of limestone and quartzite, the proportion and size of the former increasing as the mountains are approached, but east of Highwood river they are composed almost entirely of quartzite. The gradual diminution in size of the limestone pebbles and their final disappearance to the east, while the quartzite constituents still continue, is no doubt due to their inferior hardness and consequent inability to stand the wear attendant on a lengthy journey under the conditions in which it was accomplished.

"The Saskatchewan gravels and associated sands and clays in the neighborhood of Fish creek are everywhere overlain by boulder-clays holding scratched limestone and quartzite pebbles and boulders from the west, and at rare intervals small gneissic pebbles from the east."

In my own descent of Bow river, in 1881, attention was chiefly devoted to the underlying rocks, but to the above description by Mr McConnell it may be added that the existence of the Saskatchewan gravels, though obscured by slides, was suspected at some places below the Blackfoot crossing.* Above the crossing these gravels appear sometimes at the water-level and sometimes at heights from 20 to 60 feet above it, but it is probable that if carefully looked for they might be recognized at short intervals all the way down to Medicine Hat.

At Calgary, on the north side of Bow river about a mile below the bridge, a very instructive and clear section occurs. This had been examined by Mr McConnell in 1890, and was in 1894 carefully reëxamined by that gentleman and myself. It shows in descending order: †

	Feet
1. Irregular deposits of gravel and silty soil	5
2. Stratified silts, with some lenticular layers of boulder-clay; striated stones and small boulders in both	35

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* Report of Progress, Geol. Survey of Canada, 1882–'84, pp. 141 C, 142 C.

† Elevation of base of section, 3,390 feet.

	Feet
3. Boulder-clay, with some stratified silty layers and pebbles arranged in lines of stratification	20
4. Gravels	15
5. Laramie sandstones and shales, nearly horizontal	25
	100

The following details, written down at the time, further explain what is seen in this interesting section. The order followed is that of deposition, beginning with the base of the section: The surface of the Laramie rocks where composed of fairly hard sandstones is smooth and waterworn without any glacial striæ. Resting directly upon this are rather incoherent gravels with a considerable admixture of clayey or silty matter. All the stones are derived from the mountains, and most of them are quartzites (some 18 inches through), but Rocky Mountain limestone is also abundant. Nearly all are well rolled and rounded, but careful search shows traces of striation on some of the limestone pebbles. These appear to have been produced upon the already rounded stones and to have been largely obliterated afterwards by further wear. There is little or no trace of stratification in the gravels, which resemble more the deposit found in the bars or bed of some river than anything else.

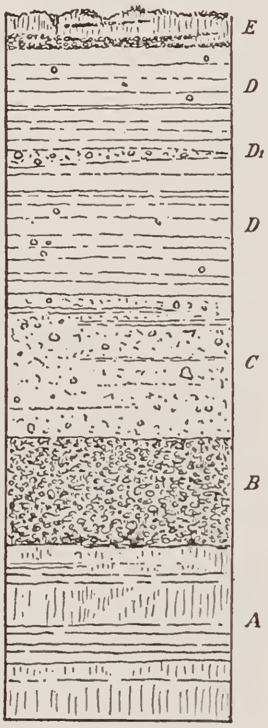

FIGURE 4.—*Section in Bank of Bow River near Calgary.*

A = Laramie rocks.
B = Saskatchewan gravels.
C = boulder-clay with silty layers.
D = stratified silts containing (D_1) a layer of boulder-clay.
E = surface gravels and soil.

The gravels are cut off above sharply on a nearly level plane, above which is a hard yellowish gray boulder-clay, often standing vertical in the face and breaking out in prismatic fragments. This contains many well striated stones and small boulders, and shows occasional lines, running for a few feet or yards horizontally of fine pebbles and sand, or of silt, which is slightly lighter in color than the rest. The vast majority of the stones are from the mountains, but a very few Laurentian stones are included. There is no marked difference between the earthy material of the gravels and that of the mass of the boulder-clay, except that the latter is more compacted, and the gravels might in fact well be regarded as a species of boulder-clay or a closely allied deposit. The boulder-clay probably varies from 10 to 20 feet in thickness within a few hundred feet.

The upper part of the boulder-clay becomes more interstratified with silts and it thus passes up gradually into the next member of the section, which forms nearly the entire upper part of the bank. The silts overlying the boulder-clay are yellowish gray in color, well bedded and frequently show minute cross-bedding between the more prominent horizontal planes. They vary a little in tint and fineness and sometimes include layers two or three inches thick, of brownish color and leathery texture, composed of almost paper-like leaves. Glaciated stones, sometimes large, occur here and there throughout the silts, and they also include at this place one or more layers of a few feet thick which are markedly stony, not very distinctly stratified and differ in no material respect from the boulder-clay except that they are somewhat less coherent. Laurentian fragments become increasingly frequent toward the top of the silts, but are never abundant at this place.*

Above the bridge and about a mile distant another bank shows these silty deposits resting directly on the lower gravels without any boulder-clay.

It is here quite clear that the boulder-clay and silts represent a single deposit which took place under varying conditions and in which the boulder-clay forms, broadly speaking, lenticular masses, not persistent and not characteristic of any particular horizon or coextensive with the region of deposit. The section is as a whole, moreover, that of a series of stratified deposits, in which evidences of tumultuous deposit and obscure bedding occur only in the case of the boulder-clay and the underlying gravels.†

Beyond Calgary, Mr McConnell writes as follows of the sections along the river :

" Four miles above Calgary the glacial deposits consist in descending order of 3 feet of gravel and soil, 8 feet silt, 2 feet boulder-clay, 1½ feet silt and 20 feet of gravelly boulder-clay. No eastern pebbles are found in this section, nor were any found in the valley of the Bow west of Calgary, notwithstanding the fact that three miles to the northwest boulders of Laurentian origin occur on the summit of the Nose hills at an elevation of 550 feet above the river at this point (3,934 feet above sealevel).‡

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*The boulder-clay in this section is evidently either the "lower" or "upper" boulder-clay of the plains. Boulder-clay holding eastern stones is here recognized for the last time in approaching the mountains by the Bow valley.

†It may here be noted that a section identical in character with that at Calgary has since been examined at Edmonton, on the Saskatchewan, abont 200 miles north, nearly in the same longitude and at an elevation of about 2,200 feet. The Saskatchewan gravels, sparingly developed, are here covered by 50 feet or more of alternating boulder-clay and well stratified silts. The boulder-clay occurs in layers of two, three or more feet in thickness. Most of the stones are included in it, and there are Laurentian and western in proportions respectively of about 1 to 2.

‡Faintly impressed terraces, like those of the Porcupines, occur at several levels upon the eastern slope of this plateau, the best marked at a height of about 3,900 feet.

"Eight miles above Calgary a section showing the following sequence was examined:

	Feet.
1. Soil and silts	15
2. Clay with layers of silt	10
3. Gravelly sands	5
4. Stratified sands	4
5. Gravelly boulder-clay	6
6. Yellowish sands	40
	80

"The clay (number 2) underlying the upper silts is peculiar and was not observed farther east. It is destitute of stratification, light blue in color on a fresh surface, very compact and highly calcareous. It probably represents the fine material produced by glacier erosion, sorted from the coarse products, and carried eastward by glacial streams until the lessening current or a lake basin allowed its deposition. The silts overlying it have the characters of a lake deposit.

"Four miles below Cochrane (30 miles from the mountains) a section shows the same glacial clay referred to above, resting on boulder-clay and overlain by silts. The boulder-clay along this part of the river ranges in thickness from 20 to 40 feet and consists of a light drab colored sandy clay filled with striated and rounded pebbles and boulders of limestone and quartzite. It is separated in places from the overlying fine clay by sandy and gravelly beds, but in others merges gradually into it. The fine clay, like the boulder-clay, is variable in thickness, ranging from 15 to 50 feet. It holds a few scattered pebbles, which are often glaciated, and are occasionally found in an upright position and at various angles to the plane of the deposit—a fact probably due to their having been dropped from floating ice. The silts have a thickness here of about 100 feet. They exhibit curved cross-bedding, resembling the kind known as flow-and-plunge structure, except that the curved layers are short, seldom exceeding six inches in length, and the surfaces are concave upward. Pebbles, some of which are striated, occur throughout the section and lumps of clay are found at intervals.

"Opposite Cochrane the boulder-clay has a thickness of 125 feet. At the mouth of the Jumping Pound, three miles farther up, it is much thinner, and is overlain by flood-plain gravels. Half a mile below Ghost river the boulder-clay is overlain by 40 feet of coarse sands and gravels, above which is 20 feet of river wash.

"From this point to the mountains, a distance of about 20 miles, the boulder-clay has been washed away in most places and the older rocks are covered directly with river gravels. Small sections, however, occur at Morley, 15 miles east of the mountains, near the mouth of a creek below old Bow fort, and possibly also at other places. The river here is unnavigable and was not closely examined.

"Bow river, in its passage through the foothills and for some distance beyond, is bounded by wide terraces floored with river gravels, which rise in an irregular manner to a height of about 250 feet above it. Traces of terraces exist at higher elevations, but the lines are not continuous. The accompanying illustration shows the outline of the valley a mile west of Morley.

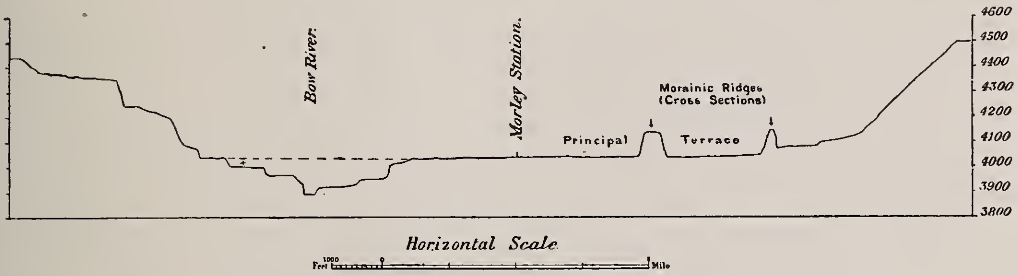

FIGURE 5.—*Section across Bow Valley at Morley.*

Showing the principal terrace, through which morainic ridges project and in which the present river-valley has been excavated since the Glacial period. At (x) a stone hammer was found in an excavation in the gravels, and it is believed to be contemporaneous with the formation of the small river-terrace indicated.

"From Cochrane west to the mountains a number of mounds and ridges, evidently of morainic origin, project through the terraces and are scattered along the slopes of the valley to a height of about 300 feet. The ridges are usually several hundred yards in length, 50 feet or more in height, and as a rule are either parallel or inclined at a small angle to the course of the valley. At Morley station such ridges and hills occupy a continuous area of fully a square mile.*

"The drift ridges are usually covered with vegetation and natural sections through them are scarce. The best sections examined were found in some railway cuttings half a mile west of Morley. The exposures here consist of hard boulder-clay of a light drab color, filled with pebbles and boulders of limestone and quartzite. The pebbles seldom exceed three inches in diameter, and while some of them are rounded and water-worn a large proportion are polished and striated. In composition the drift ridges suggest drumlins rather than ordinary moraines, but from their position there seems to be little doubt that they were deposited at the extremity and along the side of the Bow River glacier. Glacial groovings, evidently referable to the Bow Valley glacier, were found on the slopes of Bow valley south of Morley at a height of 560 feet above the river or about 260 feet above the morainic ridges just described."

Reverting to the section across the Bow valley above given by Mr

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* Cf. Report of Progress, Geol. Survey of Canada, 1882-'84, p. 146 C.

McConnell,* it may be added that the same principal wide terrace there shown by him enveloping the morainic ridges was particularly observed by me in 1881 at a point about six miles farther up the valley, with an elevation of about 4,200 feet. In my note-book it is thus described :

> "This (bench) is several miles wide and occurs on both sides of the river. It is sandy, gravelly or stony on the surface and is not a river-terrace, but must have been formed when water stood against the mountains at its level, the river from the pass no doubt bringing down the material. Its level at Morley is about 4,030 feet, giving a slope upward toward the west of nearly 30 feet to the mile."

Reviewing the sections afforded by Bow river, the principal facts shown by them are summarized as follows by Mr McConnell :

"From the mountains east to Calgary the glacial deposits are entirely of western or local origin and consist of boulder-clays passing occasionally into gravels and overlain in places by fine glacial clays and silts.

"East of Calgary the rolled gravels and associated clays and sands which underlie the boulder-clay are also of western origin, and probably represent, for some distance at least, the wash of streams flowing eastward from the Bow River glacier.

"From Calgary to a point between Blackfoot crossing and Medicine Hat the boulder-clay contains western, local and eastern material, the former greatly predominating at first, but gradually diminishing in relative quantity toward the east until it is entirely replaced by the latter, so far at least as it is capable of recognition.

"The third zone extends from a point above Medicine Hat eastward, and in it the boulder-clay, so far as known, is entirely of eastern or of local origin.

"The boulder-clays of the middle and eastern zones graduate into each other, but the relations between the middle and western zones are less clearly defined. At Calgary, the most westerly point at which mixed boulder-clay was found, it is underlain by a gravelly clay bed of western origin similar to certain phases of the western boulder-clay and undoubtedly a continuation of it, modified to some extent by water. The inferior position of this bed shows that part at least of the western drift was deposited before the advent of any material from the east; but whether the whole of it was laid down prior to the eastern invasion or not I was unable to ascertain."

Summary and Discussion.

In concluding this paper, which, because of a wish to present observed facts rather than any theoretical deductions, has attained considerable length, a few words may be added on the more obvious conclusions to

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* Cf.; also op. cit., p. 146 C.

be derived from these facts and their interrelation. These conclusions are practically such as may directly be drawn from the region itself, not complicated by attempted correlation with distant fields, nor will I venture at the present time even to compare them with a scheme of glacial events in the west which has already been tentatively advanced by me.

As implied in Mr McConnell's summary of the Bow River section, just given, it may, I believe, now be stated with certainty that the earliest sign of glacial conditions met with in southwestern Alberta is found in the evidence of the extension of glaciers from the Rocky mountains to a certain distance beyond the base of that range. These may have reached nearly to Calgary, in Bow valley, which has the largest drainage basin in the mountains, but were much less considerable farther south. A boulder-clay was at this early time laid down in connection with these glaciers, probably in part as a subglacial deposit, in part along their retreating fronts as a fluvio-glacial deposit. The latter as it is followed eastward gradually changes into the typical Saskatchewan gravels, in places associated with silty or sandy beds. All the drift material of this stage is either local or derived from the Rocky mountain side, and it is probable that the boulder-clay of this time is actually connected with the mass of the moraine ridges and hills of Bow valley and those found fringing the mountains in places farther to the south.

Above the Saskatchewan gravels rests the lower boulder-clay of my original report, containing mixed drift from the Laurentian plateau and Winnipeg basin to the eastward and the Rocky mountains on the west. Beyond the change of conditions implied by the differing deposits, no evidence has been found to show that any long time-interval occurred between the stage of the Saskatchewan gravels and that of the lower boulder-clay; nor can it be determined to what extent mountain drift continued to be supplied from the west during the deposition of this boulder-clay, as the preëxisting Saskatchewan gravels have evidently become incorporated with it in places to an unknown degree.

Above this boulder-clay, and evidencing altogether different conditions over a tract at least 50 miles in extent from east to west where cut across by the Belly river, are well stratified interglacial deposits, including locally a thin bed of lignite.

Succeeding the interglacial deposits is the upper boulder-clay, which, like the lower, contains mingled drift of eastern and western origin. Above this and forming the surface of the plains are stratified loamy, silty, sandy and gravelly deposits, which appear to have been laid down in water and in and on which are scattered many of the larger erratics met with in the district.

As already mentioned, it is not certainly known how far the lower and upper boulder-clays of the plains or either of them extend to the west. Both are found at Lethbridge, 60 miles from the mountains, and, if the line observed in sections on Highwood river corresponds with this division, both are there present to within about 15 miles of the base of the mountains and at an actual elevation of 3,700 feet. One or the other of these boulder-clays, however, extends westward along the Oldman river beyond the longitude of the Porcupine hills, and at least as far west as Calgary, on Bow river, and there is some reason to believe that it is the upper boulder-clay which is thus most widely spread.

Respecting the conditions indicated by the various deposits, the following remarks may in the first place be made:

The Saskatchewan gravels, in their composition and because of the great distance to which they have been carried from the mountains, imply the existence at the time of their formation of a considerable eastward slope of the plains, probably greater than that by which the same region of the plains is affected today. The existence of silty deposits and sands in association with them, however, shows that areas of slack water or lacustrine conditions must in some places have occurred.

The interglacial deposits give reason to believe that at the time of their deposition, as elsewhere explained,* at least a considerable tract of the western plains had become practically horizontal.

It remains uncertain to what particular period subsequent to that of the Saskatchewan gravels, and excluding that of the interglacial deposits, the traveled gravels and boulders marking the highest levels of the drift deposits on the Porcupines and foothills are referable; but it is certain that this time was one of great relative change of level, taking the form of a depression toward the west or southwest. This is rendered evident in a broad way by the occurrence of Laurentian stones to a height of 5,300 feet, or about three times that of the present summit level of the Laurentian plateau from which they came. It is reinforced by the association of these with limestones of the still lower Winnipeg basin.

Pursuing this argument a little further into detail, we may compare some of the levels at which the highest drift is found in several places in the west. In the Porcupine hills this level is undoubtedly that of a water-line, and I believe it to be so also in other places in which it has been noted.† On this assumption a relative depression to the west at this time of 900 feet is indicated between the Cypress hills and the Porcu-

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* Report of Progress, Geol. Survey of Canada, 1882–'84, p. 151 C.

† Terraces noted by Mr G. E. Culver near Saint Marys lakes, in northern Montana, may represent those here described, although no eastern drift appears to have been found upon them. Mr Culver's description appears to show that the levels are about the same. Trans. Wisconsin Acad. Sci., vol. viii, p. 202.

pines, or a slope of about 4½ feet to the mile. But if it be assumed that this level marks that of the surface of a *mer de glace*, an extension of the Laurentide glacier (as has been done by Mr Upham), a similar westward depression must likewise be admitted. In so far as such a surface might have departed from horizontality, it must have done so by sloping down toward its termination in the west. Ice standing at a level of 4,400 feet at the Cypress hills could under no conceivable conditions have been pushed up to a height of 5,300 feet at the Porcupines, 200 miles further in the general direction of its flow.* Thus, under this hypothesis, we would require to add the amount of slope of the surface to that necessary under the first mentioned assumption.†

As to the period to which this great western depression may be assigned, it is pretty clear that it must accord with one or the other of the glacial formations not already accounted for. In other words, it must have been synchronous with the lower or upper boulder-clays or with the silty deposits subordinate to them. I have elsewhere given reasons for the belief that both these boulder-clays of the western plains are attributable to the agency of floating ice,‡ but this hypothesis need not here be specially insisted on. Important bedded silty deposits are found to blend with the upper part of the upper boulder-clay, and the fact that large erratics are most abundant on the plains at the top of or overlying the upper boulder-clay, with the similarity of these to those found on and about the Porcupine hills and foothills farthest in toward the mountains, leads me to suggest that this period of greatest depression corresponded with that of the upper boulder-clay or immediately followed it.

A closer comparison of the highest levels of erratics in different parts of the field shows that the area of greatest depression, and that of greatest subsequent uplift, touches the southern part of the Porcupines and extends thence in an east-southeasterly direction, and that to this direction a series of "isobasic" lines of decreasing amount must have been roughly parallel for some distance to the northeastward. The changes in elevation seem, however, to have been accompanied by deformation of some importance, for the highest level of drift upon West butte is found to be considerably below what it should be had the difference in level been distributed uniformly in proportion to distance between the foothills and the Cypress hills, although all three of the localities are approximately in an east-and-west line. The facts are as yet too few to enable these

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* The maximum depth of ice or water covering the adjacent low country must have been about 2,000 feet near the Cypress hills and 2,100 feet near the Porcupines.

† A similar relative change of level would, of course, be equally implied on the supposition of a great western glacier-dammed lake.

‡ On the Physiographical Geology of the Rocky Mountain Region in Canada. Trans. Roy. Soc. Can., vol. viii, sec. 4, p. 63 et seq.

local differences to be worked out in detail, but others already recorded have a similar meaning.

When the highest terraces and shingle beds were formed upon the Porcupines there is further evidence to show that in the body of water of which these formed the shores a pretty definite current must have existed. Some distance to the eastward, this probably flowed southward or southwestward, but where it reached the Rocky Springs plateau the appearances indicate that it was moving nearly parallel to the border of the glaciated region in Montana,* west or to the north of west; thence it impinged upon the base of the Rocky mountains and was deflected to a northeasterly direction, a circumstance shown by the occurrence, elsewhere referred to, of pebbles of the locally developed greenstone of the mountains in some abundance on the higher parts of the Porcupine hills. Such a current may reasonably be accounted for by the prevailing direction of the winds at the time and season of the driftage of the ice.

In the case of these high-level drifts of the Porcupines the deposit of eastern and western material must have been contemporaneous. Both find their upper level at the same plane, and there are no antecedent deposits at such a height from which either can have been derived. At this time, moreover, some deposit must have been in course of formation beneath the surrounding deeper waters across which the debris-bearing ice floated, and, because of the melting of the ice and other accidents, this could not have been otherwise than a notably stony one. As already stated, this is believed to be represented by the upper boulder-clay, the silts overlying it, or in part by both.

The terracing of the Porcupines is not so pronounced as to require the long presence of the water-margin at any of the higher levels, but the well rounded character of most of the stones, particularly those from the mountains, is such as to imply prolonged attrition. The same character is notable in the vast majority of the stones included in the boulder-clays. It seems, in fact, probable that during the winter months at this period a massive ice-foot formed along the abrupt base of the mountains, upon which, in the spring, gravels from flooded streams were often discharged, while large angular limestone blocks from cliff-falls also lodged upon it in some localities. When in summer this ice broke away it would carry with it the load thus acquired.

That the glaciers which at the period of the Saskatchewan gravels protruded from the mountains must at this time have shrunk back within the range, in the southern part of the district at least, is shown by the stranding of Laurentian boulders upon the old moraines of these glaciers close up to the foot of the mountains. It is possible that the Bow Valley

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* Report of Progress, Geol. Survey of Canada, 1882-'84, p. 148 C.

glacier may still have continued to hold some importance in the foothill region, but the abundant supply of well rounded gravels, with other circumstances, renders it probable that the Rocky Mountain glaciers generally had become strictly local and relatively insignificant.

If it may thus be assumed that the higher terraces and traveled gravels of the Porcupines are approximately contemporaneous with the upper boulder-clay, all the lower and later terraces and gravel plains may be regarded as marking stages in the subsidence of this water-level from its maximum height of 5,300 feet. These, it has already been noted, are usually not strongly impressed, and there is no evidence that the subsidence was arrested long, except at one stage, which is that spoken of in the report of 1882–'84 as being at about 4,200 feet. Further examination appears to show that the terraces referable to this particular stage slope up gradually in the foothills and on approaching the mountains to a maximum height of about 4,500 feet, from which it may be argued that from the last mentioned height the water lowered its level gradually to one of about 4,200 feet, while new material was constantly being washed down by rivers from the mountains. A later and still lower, though less important, period of arrest seems to be marked by the gravel plain near Macleod at about 3,200 feet.

The first mentioned line of relative stability appears to be equally well marked in the southern portion of the region, about Waterton lake and the Oldman river, and in the northern, in the Bow valley, leading to the suggestion that the irregular uplift of the earlier stages of recovery had been succeeded along the base of the mountains by one in which further change of level occurred throughout uniformly, as compared with the actual heights of the surface found in the same region today, or with isobases changed in direction and parallel to the trend of the mountains. This later uplift may have continued, with the stranding of large boulders near the water-line from time to time, until this part of the plains reached its present condition and slope.

There is, however, some good evidence to show that in postglacial times a renewed or continued southern uplift took place. This is derived from the changes in the course of streams and slopes of their valleys, but cannot be entered into in this paper.*

In this connection I may digress so far as to mention that there is a somewhat notable correspondence between the higher levels of terraces on both sides of the Rocky mountains and continental watershed. It is found in the southern part of the interior plateau of British Columbia

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* Report of Progress, Geol. Survey of Canada, 1882–'84, p. 150 C; Annual Report, Geol. Survey of Cananda, vol. i (n. s.), p. 75 C; Physiographical Geology of the Rocky Mountain region in Canada, Trans. Royal Soc. Canada, vol. viii, sec. 4, p. 63.

that the highest terraces occur at elevations of from 5,500 to 5,300 feet; that below this there is a remarkable paucity of terraces down to about 4,450 feet, between which and a height of 4,300 feet another well marked group of old water-lines appears. These facts are fully described in my forthcoming report on the Kamloops map-sheet. The circumstance may not be more than a coincidence, but it is certainly a striking one and one worthy of further investigation.

As it has already been stated that no certain evidence has been found such as to show that the lower boulder-clay may not be that extending farthest west and in toward the base of the mountains, it may be appropriate now to mention the hypotheses which present themselves on that assumption. If the lower boulder-clay holds this position and was deposited contemporaneously with the high-level erratics and gravels, the upper boulder-clay may very well have been laid down in the body of water standing later at the inferior levels of from 4,500 to 4,200 feet and indicated by the well marked terraces and gravel plains already alluded to. This hypothesis, of course, assumes that a boulder-clay may be deposited from floating ice, and to me it appears probable that a material of this nature may have been formed in any one of three ways, namely, beneath a glacier, about the edge of a glacier as a fluvio-glacial deposit, or below a body of water charged with floating ice.

According to still another possible hypothesis, it may be supposed that while the lower boulder-clay is that stretching farthest west and spreading around the base of the Porcupine hills, the high terraces may be due to a subsequent flooding about the time of the upper boulder-clay. This, however, does not appear to accord well with the facts, for in this case there is no recognizable deposit in the lower parts of the flooded district near the Porcupine hills to represent this period of submergence.

Respecting the actual western limit of eastern erratics, the investigation here reported upon seems to show that the line marked upon the map accompanying the report of 1882–'84 nearly corresponds with observed drift of this origin in the boulder-clays proper, slightly exceeding this to the south of the Porcupines and falling a little short of it to the north, but that scattered erratics occur in places considerably farther to the west. These are found upon the higher ridges and hills, and if present equally in the valleys have there been concealed by a later wash from the mountains. Behind the Porcupines, the occurrence of such erratics is in inverse proportion to the amount of shelter afforded on the east by the higher parts of these hills—a fact equally explicable under any hypothesis of their deposition; but the occurrence of such sporadic erratics renders it difficult to draw any precise western line, and it is possible that renewed investigation of the higher foothills may in some places result in their occasional discovery even farther to the west than they have yet been observed.

Another fact of importance, and one which impressed itself on the writer in the course of the recent examination, is the following: Except in the case of the moraines evidently referable to glaciers of the Rocky mountains, which we have found reason to assign to a very early period and which save in the case of Bow valley are closely confined to the base of the mountains, the more obvious evidences of the work of glaciers are conspicuously absent in this entire region of the foothills and Porcupine hills. The highest and farthest limits of the drift are not marked by moraines, and moraines, drumlins, kames, and eskers are, with the above exceptions, entirely wanting. This is very striking when comparison is made between this region and that of British Columbia or the Laurentian plateau, both of which are known to have been overridden by vast glaciers.

Within the past year Professor T. C. Chamberlin has formulated and named a series of stages in the glacial history of North America, and although the author of the classification would probably be the first to admit its provisional character, it has undoubtedly already been of considerable service in suggesting a basis of arrangement and in fixing the direction of future work. Thus it will be appropriate briefly to note here in conclusion what appear to the writer to be the probable relations of the glacial deposits of Alberta to this general classification.

The "lower" boulder-clay may, it is believed, be regarded as representing the Kansan formation, while the interglacial deposits, best developed along the Belly river, are supposed to be contemporaneous with the post-Kansan interval. The "upper" boulder-clay of the western plains may then be identified with the Iowan formation and like it is associated with abundant silty beds. The Wisconsin formation is in all probability not met with in the extreme west, but its limit in this direction may be marked by the Missouri Côteau, which in Canadian territory extends from the forty-ninth parallel to the North Saskatchewan and indefinitely beyond in the farther north. The post-Iowan interval, in this case, appears here, as in the region farther east, to be marked by the erosion of important interglacial valleys, which find their limit at the Côteau and its systems of drift ridges and hills.* No deposits like the Côteau occur in connection with the western terminations of the "lower" or "upper" boulder-clays.

Reverting now, on the basis of the above correlation, to the Saskatchewan gravels and the "western" boulder-clay, it will be apparent that these must represent an antecedent and unnamed stage of glaciation in

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* Geology and Resources of the Forty-ninth Parallel, p. 230.

North America. This, with scarcely any doubt, may, from the observations given in this paper, be regarded as that of the maximum of the Cordilleran glacier, and to it I would propose to apply the name of the Albertan stage or formation.

The Saskatchewan gravels may very possibly represent the Lafayette formation of the eastern states. This correlation has been suggested by Mr Upham, but it is prudent as yet to hold it subject to correction, for there appears to be some danger of referring to a single formation various remote gravelly deposits found below boulder-clays. It is, however, maintained by Professor C. H. Hitchcock that the Lafayette represents the earliest epoch of glaciation in eastern America, which in itself appears to give at least some force, with our present information, to the hypothesis that we find the greatest development of glacial agencies at this same time in the maximum spread of the Cordilleran ice-sheet, while only at a later date did the center of ice distribution migrate to the Laurentian plateau. Such a migration must have been in intimate connection with the vast relative changes of level, of which some striking evidence is found in the particular region now under consideration.

In these later pages of this paper it may be that conjecture has in some instances been pushed too far, but so long as it is understood to be merely a tentative discussion of the facts given, without comment, in the body of the paper, it cannot be misleading. In this southwestern part of Alberta it is at least manifest that the records exist, more or less obscured and interwoven, of a complicated series of conditions during the Glacial period, the final reading of which must add materially to our knowledge of the glacial history of the continent as a whole.

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GEOGRAPHICAL EVOLUTION OF CUBA

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(Read before the Society December 27, 1894)

CONTENTS

Introduction.

In Cuba there are mountains higher than any on the eastern side of North America; extensive plains as level as those of the Atlantic coast; valleys formed at the baselevel of erosion, and deep canyons carved out by the youngest streams; the remains of enormous beds of limestones mostly swept off the country, and coral reefs and mangrove islands extending the coastal plains into the sea; sea-cliffs, caves and terraces of great and little elevation; drowned valleys deeper than the fiords of Norway indenting the margin of the insular mass; caverns innumerable and rivers flowing underground; rifts through mountain ridges and rock-basins; tilted, bent and overturned strata, dislocated and faulted in modern times, so as to make youthful mountain ranges; metamorphic rocks and rocks igneous, and these again altered to secondary products; old baselevel plains or these modified and reaching across the island, having insular ridges of older formations rising out of them, and with the surfaces scarcely incised by the streams; residual soils from the decomposition of the rocks and sea-made loams and gravels; in short, so rapidly are the geologic forces working that one can see a greater variety of structure and learn more of dynamic geology in Cuba than on more than half of the temperate continent.

Owing to the apparent connection of the Antillean region with the American continent in recent geologic times, the writer visited Cuba in order to ascertain the relationship of the atmospheric degradation of that region to the later geologic formations. In his studies almost the only assistance received was found in the difficultly obtainable geological map of Cuba by De Castro and Salterain y Ligarra, published in Madrid in 1881, "Apuntes para una Descripcion Fisico-Geologica de las Jurisdicciones de la Habana y Guanabacoa," by Salterain, Madrid, 1880; and "Impressions of Cuba," by G. F. Mathew.* This last classic paper relates to the region of Cienfuegos. A few other scattered notices will be referred to in the text.

General Topography.

Cuba is 750 miles long and from 25 to 120 miles wide. In the western part of the island there are ridges of mountains which culminate in a

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*Canadian Naturalist, vol. vii, 1872, p. 19.

point with an altitude of 2,500 feet, but the principal topographic relief is along the southern coast of the eastern extension of the island, where Pico Tarquino rises from the Sierra Maestra to an elevation of 8,400 feet. The central portion of the island is generally a plain from 200 to 400 feet above tide, which bears many scattered and interrupted ridges, like islands in a sea. To this portion of Cuba the present study is chiefly confined.

The northern coast, from Havana to Matanzas, 53 miles, is high, and rises out of an open sea, but both toward the east and west the low coastal plains extend as submerged shelves for 10 or 20 miles farther, and are surmounted by coral keys, mangrove islands and shallow lagoons. The same features are repeated upon the southern coast, where, however, the submerged portion of the island, often covered by not more than 5 or 10 feet of water, forms a broad shelf, as shown on the map. There is, however, an exception between Cienfuegos and Trinidad, where the shelf is incised by the gulf of Cazones. West of Cienfuegos the Zapata peninsula is a marshy plain over a hundred miles across the front.

FIGURE 1.—*Map of Cuba.*

Between Cienfuegos and Trinidad city there occurs the mass of Trinidad mountains, with diameters of 30 or 40 miles. Their altitude is 1,500 or 2,000 feet, with Pico Potrerillo a few hundred feet higher. From some directions the outline appears somewhat regular, but from others the alternating valleys and ridges produce a serrated appearance (see figure 6, page 83). The upper valleys are former baselevels of erosion, as shown in figure 2, which have been disturbed by recent elevations, for the small streams are only now cutting back their canyons hundreds of feet in depth. Thus the Rio Caburi, a small tributary of the Rio Negra, has already excavated a canyon 600 feet deep. Only the larger streams, such as the Rio Juan, have excavated deep gorges far back in the elevated valley floors of older date. The Trinidad mountains form the highest reliefs in central Cuba, and also the most picturesque scenery of the island.

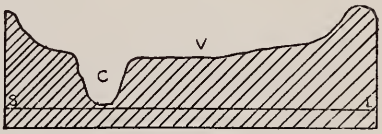

FIGURE 2.—*A high baselevel Valley.*

This valley (*v*), more than a mile wide, is being incised by the extension of the canyon (*c*) of the Rio Caburi.

On the northern side of Cuba the highest point of the interrupted ranges of mountains is Pan de Matanzas, 1,277 feet above tide. It is terraced and sculptured with sea-caves and rifts (see figure 8, page 87). The other inferior and scattered ridges in the central portion of the island trend southwestward, but they are not usually parallel to the coastline. They are the remnants of an early degradation before the formation of the present plains, which occupy much of the central portion of the island, and which are so level that for long distances no irregularity appears on the horizon. The elevations of the plains between Havana and Matanzas, and for a few miles eastward, seldom exceed 300 or 350 feet, and the ridges which rise out of them may reach altitudes of 300 or 500 feet higher. Farther east, in the vicinity of Colon, the plains are not more than from 100 to 200 feet high, while in the central part of the island, between Cienfuegos and Santa Clara, the land again rises to as much as 400 feet above the sea. Although level to the eye, the plains slope toward the shores of both sides of the island.

The streams in this part of the country are in very shallow depressions, without the appearance of valley structure, except as they near the coast, where in a distance of five miles they may descend 300 or 400 feet, and form amphitheater-like valleys two or three miles wide. In many localities the drainage is carried off by subterranean outlets. Streams, after flowing at the surface, disappear and again emerge. The Rio Negra north of Trinidad illustrates this feature.

Between Havana and Matanzas sea-caves may be seen at an altitude of about 350 feet upon the landward side of a higher ridge, thus showing a recent submergence of the plain.

Hydrography off the Coast.

The submerged coastal shelves have been referred to as continuations of the land features, but across these drowned lands the soundings are infrequent in many localities, yet in others they are abundant enough to show some valleys of great depth. The most notable incision in this enlarged insular mass is the gulf of Cazones, of which Cochinos and Xagua bays are branches (see map, page 69). Near the head of the gulf the drowned valley is 2,256 feet deep, and increases to over 7,500 feet before reaching the mouth. The length of the incision is 70 miles. The land about the head of the gulf is low, and the valley has there been filled with recent formations. The present low land was a plateau into which the now drowned valley extended as far back as the present head of Xagua bay. The western side of the fiord is bounded by the submerged portion of the island, where the water between the keys and mangrove islands is, except in occasional channels, often only a few feet deep. On the eastern side the gulf is bounded by the present shores of the island. This fiord descends farther seaward and joins the Bartlett deep. There are evidences of a similar fiord south of Guantanamo, which is east of Santiago. The channel separating Cuba from the Bahama banks is a valley less than 1,800 feet deep in its shallower portions, and consequently no extraordinary fiord could be expected.

Matanzas bay is a land-locked channel three or four miles in length. It is simply the continuation of a partly filled valley, and the bay soon reaches a depth of a thousand feet (1,434 feet at its mouth) before joining the outer fiord. Baracoa bay is over 700 feet deep. The valley at Trinidad and many canyons forming outlets for bays are from 100 to 200 feet deep. Cabanas and other bays pass into very deep fiords, but often the soundings are only sufficiently numerous to indicate their presence and not their character.

Many of the bays are from one to ten miles long and form broad basins from which there are very deep though narrow outlets. Thus Havana bay is about a mile and a half wide, with its outlet through a low limestone barrier only 900 feet wide and 60 feet deep. Xagua bay (see figure 10, page 91) occupies the lower part of a valley 12 miles long and three or four broad. Its depth varies from shoals to 100 feet, but it empties into the sea through a rock-bound canyon 168 feet deep, which in the narrowest portion is only 1,200 feet wide. This bay may be taken as one of the finest types and its origin will be described hereafter.

Geologic Basement.

METAMORPHIC FORMATIONS.

De Castro and Salterain assign the formations of Trinidad mountains to the Paleozoic group, but there appears to be no certainty as to their age. They are composed of a semicrystalline limestone of fine texture and blue color, resembling externally some Ordovician rocks; so also do the associated black slates. The limestones are somewhat micaceous and are composed of small glassy calcareous particles in a dark matrix, but in their internal structure they are not like our Paleozoic limestones. Some of them become micaceous limestone-schists, so closely resembling mica-schists that there is danger of their being mistaken for them.

The strata of Trinidad mountains are highly disturbed, being not only uplifted but also bent and overturned, with the beds dipping in variable directions. The modern topographic surface appears independent of the bedding, for the valleys and watercourses which traverse the mountain are quite independent of the folds and structure of the strata, but at the same time the erosion has developed bold reliefs, so that the serratures of the surface are dependent upon the durable remnants of the upturned strata. No conglomerates were observed in the exposures visited.

Whatever their age, the Trinidad mountains constitute the oldest rocks of central Cuba, but the formations were generally removed by denudation before the later accumulations, which are nowhere else penetrated by similar rocks. Where the mechanical materials of the Trinidad mountains came from, whether from strata since buried beneath newer deposits or from the continental extensions, cannot now be determined.

IGNEOUS FORMATIONS.

Forming some of the ridges and also the rugged valleys there are diorites and disturbed strata of serpentine, all of which are greatly decayed where the natural surfaces are exposed. There are also a few granitic rocks. These formations are included within the area of Cretaceous distribution and have been exposed in narrow belts in many portions of the island, and farther east in broader zones, on account of the removal by denudation of the overlying Cretaceous and Tertiary formations. The characters of the rocks appear constant, so that their history in one part of Cuba may probably be applied to the whole island. The upturned beds of serpentine have been extensively quarried at Havana, and the formation can be seen in the Yumuri valley near Matanzas, near Xagua bay, about Santa Clara, etcetera. The igneous rocks underlie Cretaceous deposits, but nothing is definitely known of their age, so that they may belong to the early Cretaceous or to older formations.

Cretaceous History.

LOCAL GEOLOGIC CHARACTERISTICS.

In general.—At the commencement of this period, so far as the records have shown, there were only a few insular masses of limestones and mechanical deposits in central or, indeed, most of Cuba. There were probably some islands of igneous rocks, but generally these are only exposed by subsequent denudation.

Trinidad region.—Lying against the eastern flanks of Trinidad mountains and constituting much of the floor of Trinidad valley, there are extensive accumulations referable to the Cretaceous system. The lower members are calcareous, glauconitic and gray sand or friable sandstone, composed of both angular and water-worn grains of quartz. They are frequently exposed at the base of the Tertiary limestone ridges which separate the valley from the sea. At the railway bridge west of the city of Trinidad the beds dip 30° south, 25° to 45° west. Owing to the variation of the dip and the faulting, it is not practicable to measure the thickness, which, however, must be considerable, for the formation underlies much of Trinidad valley, which is 3 miles wide and 18 miles long.

Overlying the sandstones, there are some limestone beds, succeeded by other beds of sandstone, which in turn are surmounted by heavy masses of limestones. The sandstones are fossiliferous. A flag-like plant, resembling *Typha* (identified by Mr Knowlton), was collected, but the formation was not carefully searched for fossils, which are found in the same series west of the mountains.

As best exposed at the railway tunnel the overlying limestones occur in undulating and very much broken and jointed beds, so that the dip cannot be everywhere defined, but where recognizable the direction varies from 20° to 45° west of south. The inclination of the beds diminishes toward the northern end of the section. The rock is a fine grained, compact and semicrystalline limestone, of drab color chiefly, but yellow and whitish tints also occur. The general appearance is older than that of the Tertiary limestones. Some conglomerate is included in the lower beds at the tunnel. The thickness reaches a few hundred feet, but a close determination is not possible. The highest altitude at which these beds were seen reaches 400 feet above tide, where they dip 40° south, 60° west. The exposed and fissured surfaces are often thickly coated with incrustations of ferric and manganese oxides.

Cienfuegos region.—The same formation occurs on the western side of the Trinidad mountains, and has been well described by Mr G. F. Mathew in the paper already cited. As this paper is not easily obtained the writer feels justified in quoting freely from Mr Mathew's work, as his observations are confirmed:

> "On both sides of the Damuji a series of strata is exposed, consisting chiefly of limestones, but apparently separated into two bands by an intermediate body of sandstones. . . . The limestones . . . cropping out of the ridge west of the Damuji are clearly underlain by sandstones holding Cretaceous fossils, and, although subcrystalline, fine grained and homogeneous, cannot be regarded as primary. Their lower beds are gray and impure, but did not yield any recognizable fossils; the gray grits and sandstones, however, upon which they rest contain shells of the genera *Conus* and *Oliva*, several small, undetermined bivalves and a number of small echinoid forms resembling *Citlerites*. These organisms were observed in the sandstones on the hillside, just above the buildings of the Constancia estate, where both the limestones and sandstones dip westward at a very low angle. I was informed that the subcrystalline limestones of this group rise to the surface in the Zapata swamp (which the writer has seen near Yaguaramas). . . .
>
> "I observed the arenaceous strata of this region at two points in the river valley, which would, if connected, carry them diagonally across the stream. The first of these places met with in ascending the river is the passa or ferry on the Cienfuegos

road. There are here gray and buff sandstones, containing shells of the genera *Exogyra*, *Ostrea* and *Inoceramus;* also at Limones, a farm in a little valley farther up, there are beds of dark and gray sandstone holding shells of the genera *Ostrea* and *Inoceramus*. The sandstones are accompanied by a brown conglomerate holding pebbles of feldspar, porphyry and diorite. The limestones of the Constancia landing and Concepcion estate (ravine near the landing) . . . lie along the eastern side of the arenaceous band seen at the Constancia buildings and the ferry. They are mostly of a pale buff tint, and are replete with organic remains, being in fact Hippurite limestone. This type of shell (*Hippurites*) of several species, with *Caprinella* and *Caprotina* (?) abound in them, and they also contain corals and several kinds of univalve and bivalve shells, among which are a large *Oliva*, a *Conus*, an oyster of the type *Ostrea cristata*, *Echini* and sponges.

"One feature of remark in the Cretaceous rocks of the district of Cienfuegos is the evidence they give of the extent to which the hardening process has gone on in them. This condition of the beds is not limited to the district on the Damuji which I have spoken of, but characterizes them over a large area, for in hardness and coherence they resemble rocks of the Carboniferous."

Mr Mathew also emphasizes the stupendous changes of terrestrial movements in the later geologic times throughout the West Indian region.

Havana region.—In the vicinity of Havana and eastward, denudation has removed the Tertiary formations and exposed large areas of the same strata as those seen at Trinidad and Cienfuegos. Whether all of the limestones, such as those described, belong to the Cretaceous or not is an unsettled question, one which Salterain, who has done more work in the Havana region than any other geologist, has not been able to answer. The rocks seen in the Havana district appear less crystalline than those observed on the southern coast, but the strata are much more faulted and jointed than farther southeast.

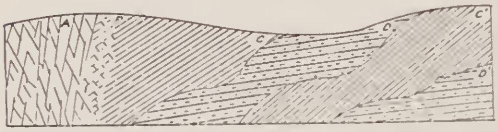

FIGURE 3.—*A Section along Railway on the east Side of Havana Bay.*

A = jointed and broken limestone; *C*, *C* = beds of the sandstones faulted into positions between beds of marls = *D*, *D*.

In the Havana district there is a lower calcareous glauconitic sand resting on the serpentine and associated rocks. Overlying the sands there is a calcareo-magnesian marl or limestone which in places is so faulted and jointed as to make it impossible to determine the dip of the strata (see *A*, figure 3). In one locality the dip is clearly 70° south, 30° west, but it is difficult to determine whether the southwestern or northeastern dip prevails. From the section of these rocks seen along the railway west of Havana, it would appear that these accumulations, probably Cretaceous, are very thick.

In the Yumuri valley, east of Colon, in the Santa Clara district, etcetera, these Cretaceous deposits are seen in narrow belts, where they have been exposed by denudation.

GEOGRAPHIC FEATURES OF THE CRETACEOUS PERIOD.

The general absence of sedimentary and calcareous formations beneath the Cretaceous sands and the widespread foundation of igneous rocks under them lead to the inference that Cuba was subjected to extensive erosion during at least the earlier Cretaceous period, if not before. However, the topography then produced has been generally obliterated so as not to be prominent in the later physical conditions of the Antillean region. The pre-Cretaceous baselevel character of Cuba bears a close resemblance to the pre-Cretaceous baselevel plains of the southern states, which were composed of Archean rocks and extended far seaward of their present limits. Indeed, it would not be a violent suggestion to suppose that the continent extended to Cuba just before the commencement of the Cretaceous period.

Whether the post-Cretaceous elevation was at the close of that period or in the earlier Eocene has not been determined, for some of the semicrystalline limestones provisionally grouped with the Cretaceous formations may belong to the later period. The degradation which affected the Cretaceous accumulations was much less energetic than that preceding the deposition of these rocks, as the sands and other rocks, although easily denuded, are yet both extensive and of considerable thickness· The preservation of the soft Cretaceous deposits is in strong contrast to the general removal of hard rocks, like those of Trinidad mountains, during the earlier period of erosion.

Where not covered by the Tertiary limestones the Cretaceous formations are generally concealed beneath the black or mulatto, residual soils formed by the decay of the calcareous rocks or the accumulation of the more recent sands and gravels.

Eocene and Miocene History.

LOCAL GEOLOGIC CHARACTERISTICS.

In general.—Resting upon the greatly disturbed and eroded surfaces belonging to the Cretaceous system there are extensive beds of limestones with which some mechanical deposits are associated. These Tertiary rocks constitute widespread formations of considerable, but variable, thickness, as they have been subjected to enormous denudation subsequent to their deposition.

While these Tertiary beds can, upon paleontologic grounds, be separated into the Eocene and Miocene systems, they constitute, however, a physical unit, apparently without important stratigraphic breaks.

Matanzas region.—Between Havana and Matanzas the Tertiary limestones form prominent ridges surmounting a country which is from 300 to 400 feet above the sea. These ridges are commonly low and interrupted, but at a point about 10 miles west of Matanzas they are rendered conspicuous by two butte-like masses, of which Pan de Matanzas, rising to 1,277 feet above the sea, is the higher (see figure 7, page 87). Eastward of the Pan the ridges become lower, but appear to rest upon the margin of an old baselevel plain of about 400 feet altitude, out of which the Vale de Yumuri is excavated. At Matanzas the Yumuri river has recently cut a canyon across the ridge and exposed the best section of Tertiary formations the writer has seen in Cuba. It is shown in figure 4. The section extends from the church near the mouth of the river along the gorge to the Yumuri valley. The canyon is only about 300 feet wide, and the walls reach an elevation of about 250 feet at a short distance from the river. This canyon will be explained later.

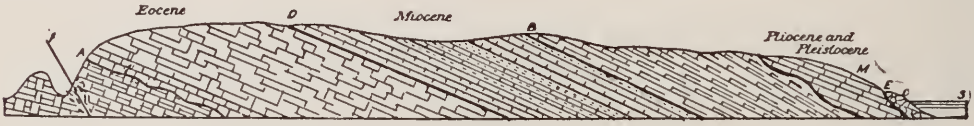

FIGURE 4.—*Section along Yumuri Canyon.*

S = sealevel; *E-C* = raised modern coral reef; *M* = Matanzas (Pliocene?) limestones resting unconformably upon the Miocene; *B* = undulations in mechanical beds; *D* = base (?) of the Miocene; *A* = undulations in Eocene beds; *F* = fault-beds shown in their natural dip.

The length of the section is 3,800 feet in a direction at right angles to the strike.

From the fault near the northwestern end of the gorge the valley opens out, and accordingly the lower Tertiary beds are lacking, through removal, on the northern side of the gorge, but upon the southern side of the valley they are further exposed for half a mile or more. The dip at the southeastern end of the section, in what have been called by the author Matanzas limestones, is 13° to 15° north, 10° to 20° east. The upper beds of the underlying and unconformable Miocene strata dip 30° south, 30° east, but this inclination is reduced in the lower beds to from 20° to 25°. At the fault near the inner end of the gorge the adjacent beds, dipping at 60°, show dislocation, but beyond the location of the fault the dip of the beds becomes normal. Reduced to vertical measurement, the formation shows the following section:

PLIOCENE (?) (MATANZAS):	Feet
White and creamy earthy fossiliferous limestones with some calcareous pebbles and fragments	150

		Feet
MIOCENE:		
Chalky and coral limestones in beds of different thickness	450	
Gray stratified sand	8–10	
Coral-bearing limestone	100	
Sand and conglomerate	40	
Limestone	30	
Sandy stone	30	
White limestone	20	
Creamy white, very hard limestone with casts of lower Miocene shells abundant	110	
		790
EOCENE:		
Rough, compact whitish limestone with vesicular surface and the thick stratum penetrated by numerous caves	480	
Buff colored earthy limestone, weathering to rounded surfaces and resting on a slight unconformity	100	
White soft limestone with some layers showing unequal hardening	180	
		760
Total thickness above the fault		1,700

Beneath the fault, the equivalent vertical throw of which is between 250 and 400 feet, there is an extensive development of Eocene limestones which may be roughly estimated in excess of the beds above the fault at from 500 to 800 feet. The total thickness of Tertiary rocks is therefore from 2,200 to 2,500 feet.

There is a slight unconformity between the Miocene marl and sand layers.

At Pan de Matanzas, about eight miles west of the above section, the thickness of limestone is about 1,000 feet, but denudation appears to have removed most, if not all, of the Miocene strata. The Pan is on the side of an anticline opposite to that where the section near Matanzas was examined. At the Pan the strata dip 10° north, 20° west. The features of the post-Miocene erosion will be noted later. The Miocene strata are moderately rich in fossils, both in the upper and lower parts of the formation. In some of the beds, especially the higher, corals in small colonies are common. The shells are most abundant in the lower beds. The following species were collected and kindly determined by Dr W. H. Dall. The corals were not determined.

Cardium (near *isocardia*) *densleonis* (?), Guppy.
Siliquaria vitis (?), Conrad.
Balanophyllia sp.
Venus blandiana (?), Guppy.
Cerithium burnsii, Dall.
Turritella altilira, Conrad.
Turritella sp.
Conus (probably *planiceps*), Heilprin.
Pecten nodosus.
Gastrochæna sp.
Chama arcinella (?), *Lam.*
Arca sp.
Lucina sp.
Psammobia, sp. not yet named (like *Chipola*).
Pectunculus (near *pennaceus*), Lam.
Thracia (belonging to subgenus *Cyathodonta*, Conrad), n. sp.

It should be noted that the shells are only preserved in the form of casts, and this condition renders their specific determination difficult, but Doctor Dall says he has no doubt of the age of the assemblage of fossils.

There is a strong lithologic difference in the characters of the strata above and below the line where the division between the Miocene and the Eocene is placed. The Eocene beds bear a close resemblance to the fossiliferous strata near Havana, and, indeed, to the Vicksburg beds of the southern states. If the lithologic separation of the two divisions of the Tertiary strata be not wholly supported by the paleontologic, yet it has no bearing on the sequence of physical events presented in this study.

At several points along the Union railway between Matanzas and Havana good sections of the Tertiary formations are exposed in the sides of the valleys. The strata dip at only moderate angles, but several anticlines and synclines were observed, such as those seen near San Miguel.

Havana region.—Salterain has treated the Tertiary rocks at considerable length in his studies about Havana. Like the rocks at Matanzas, the Eocene limestones are harder and more siliceous than the Miocene deposits. The strata form ridges along the coast and appear conformable. The lower beds unconformably succeed the Cretaceous strata already described. The beds dip at from 12° to 15° northwestward. The Miocene beds are earthy, as at Matanzas, and in part porous with the fossils in the form of casts or moulds. From five quarries Salterain collected forty species of Miocene fossils, and from seven other localities he obtained forty-four species of Eocene forms. The lists of these fossils appear in his paper, and Doctor Dall considers that the respective formations were correctly defined.

Owing to the proximity of the Tertiary formations to the sea, the streams have excavated a broad amphitheater out of the elevated plateau, so that in the erosion of the Havana basin the Tertiary formations have been largely removed, with the consequent exposure of the Lower Cretaceous and other beds. According to Salterain's estimate, the Eocene beds aggregate 200 feet and the Miocene 160 feet. These estimates exclude all of the limestones which were involved in the post-Cretaceous disturbances. Near a quarry southwest of Havana there is an isolated mass of conglomeratic limestone dipping 30° southwest, or at a greater angle and in another direction than that prevailing in the Tertiary limestones. The Tertiary limestones give rise to a residual soil like red loams.

Sagua le Grande region.—This is a leap of 150 miles to the east of Havana to a locality situated on the northern side of the island. In this part of the island the country is a low plain of great extent, out of which, southwestward of the city, low ridges rise. These ridges are composed of Tertiary limestones with their surface greatly eroded, and often levelled so as to form the plain reaching to the interior of the island. Along the railway and along the river the strata are exposed and show variable inclinations up to 60° or 70° in a direction south 30° west, and in one place the beds are vertical. Lying upon this floor there were enough patches of Matanzas marl to show that the pre-Matanzas erosion was very extensive, and even this later marl has been mostly removed by later denudation.

Cienfuegos region.—Cienfuegos is situated on a plain rising toward the interior of the island, but in the intervening region the country is undulating. The underlying materials are composed of soft yellow marls and incoherent sandstones. The beds dip from 20° to 30° southward. The sandstones occasionally form a conglomerate 20 or 30 feet in thickness. Of this section Mr G. F. Mathew says:

> "The geological formation to which the yellow and buff-colored beds underlying Cienfuegos belong appears to be one of great thickness. I have traced it in a northernly direction as far as Caunau, four miles from Cienfuegos, and I did not then reach its limit. This was in a line nearly at right angles to the strike of the beds, and the intervening strata where exposed appear to have a regular dip. The middle of the series consists of beds finer, more clayey and apparently more calcareous than those in the two places named [elsewhere]. At Caunau the strata are quite firm and compact, becoming a coarse sandstone. For a mile or two back of Cienfuegos there are numerous fossiliferous layers in the more clayey parts of the series, from which I obtained the following forms: *Belanus* sp.; *Dentalum* (?), *Ostrea*, seven species; *Anonia* sp.; *Pecten*, five species; *Echinoids*, of two species (one a *Scutelloid* form); also a large *Orbitoides*, a shark's tooth, and parts of the test of a crab, including the claws and carapace. Mr J. Lechmere Guppy, of Trinidad, West Indies, who has kindly examined these fossils, says they are probably of Miocene age. The formation in which they occur is evidently one of great magnitude and importance. . . . I should think it is a mile in thickness where I crossed it. It is probably limited by the Trinidad mountains to the east, and does not appear on the lower part of the Damuji, where the older series comes to the surface."

This estimate of the great thickness may in part arise from concealed faults, as the section is very much covered by soils, etcetera. Moreover, it would appear that the Eocene equivalents are included in the estimated thickness. The unusual mechanical character of these accumulations is explained by their occurrence near the base of the Trinidad mountains, which is the oldest land mass in Central Cuba, and the adjacent extensive deposits of Cretaceous sands.

Trinidad region.—In front of the Trinidad mountains, and extending thence for a distance of 15 or 20 miles eastward of the city of Trinidad, there is a ridge of coastal mountains consisting of a succession of peaks arranged in echelon (see figure 5), and these separate Trinidad valley from the sea. The peaks rise 600 to 700 feet above tide, with the intervening depressions reduced to 300 or 400 feet. The ridges are composed of Tertiary limestones resting upon the Cretaceous deposits.

The Santo Espiritu mountains, at a somewhat higher altitude than the coast range, and extending inland, are also composed of Tertiary formations. The trend of the echeloned coast range is south 70° east. Lookout peak, back of the city of Trinidad, is 740 feet high. Near its summit there are beds of fine conglomerate composed of rounded quartz pebbles an inch in length. There are also limestone pebbles three times as large. From the decay of the formation the surfaces of the rocks become covered with gravel that might be mistaken for a more recent deposit. Other beds are soft white marly limestones. The dip of the strata at Lookout station is 15° or 20° east of south, but lower down upon the flanks of the mountain the Cretaceous (?) limestones incline at high angles toward the southwest. Three miles east of Trinidad the Tertiary formations dip at 20° southeast. The Tertiary rocks do not exceed a few hundred feet in thickness, as they have suffered an enormous amount of erosion.

FIGURE 5.—*The coastal Chain of Tertiary Mountains dislocated by Faults.*

F = the northern side presents precipitous slopes, while the southern descent is gentle.

The different character of the Tertiary accumulations on the two sides of the Trinidad mountains is notable, and may have arisen from the direction of the currents or from the deposition of the two sets of beds not having been synchronous. No attempt has been made to separate the different members of the group, as the fossils are very scarce, those found in the caves having been carried there at a recent day. The Tertiary limestones are very much honeycombed by rain washes, and they are further characterized by numerous large caves. Only fragments of the overlying Matanzas marls remain upon the eroded surface of the older Tertiary rocks, except near the coast.

GEOGRAPHIC FEATURES OF THE TERTIARY PERIOD.

In the early part of the Tertiary period a long, narrow island extended from the Trinidad mountains eastward. Between the Trinidad mountains and those in the most western portion of Cuba there was a broad sea, out of which rose a few islands. The depth of the submergence was variable. At Matanzas it exceeded 1,300 feet and in the Sierra Maestra the depression reaches at least 2,300 feet (Kimball). In some portions of Cuba there is evidence that the land was high in the early Eocene, but apparently depressed at the end of that period, which merged into the Miocene. In places the fossils indicate, according to Salterain and Gabb, that there was a submergence until the close of the Miocene period. However, the Miocene period was characterized by some important changes of level, for mechanical sediments often replace the calcareous. Several years ago Professor W. O. Crosby found radiolarian earths at Baracoa, which were identified by Dr J. W. Gregory. These have been regarded as of deep-sea origin. Samples of the earth were kindly given the writer by Professor Agassiz, for whom it had been collected by Mr R. T. Hill. Their occurrence in other islands of the West Indies was better known, and they have been correlated with the Barbadoes deposits of Mr Jukes-Browne.* If these radiolarian earths were deposited concurrently with those of the Barbadoes and the Miocene earths of the Atlantic coast and Jamaica, then it would appear that portions of Cuba were depressed to abysmal depths before or during the earlier Miocene period, for the present writer has found that no radiolarian earths occur in the succeeding Pliocene deposits which rest upon the greatly denuded Miocene limestones of Cuba.

Since the above was written Mr Hill has published stratigraphic evidence of the Baracoa earths underlying Miocene beds.

Pliocene History.

MATANZAS FORMATION.

In patches or in more continuous belts there are white and stained limestones and marls constituting a formation resting unconformably upon the greatly eroded surfaces of the older Tertiary and the Cretaceous strata already described. The more chalky beds become case-hardened upon exposure. The formation contains more or less fragmental material, derived from the broken remains of the older Tertiary rocks, and sometimes water-worn pebbles of the same material. Where unconformity is not recognizable there is often difficulty in distinguishing these calcareous beds from the Miocene marly rocks, but the formation is fossiliferous.

In the Havana region Salterain catalogued the following fossils which he found in this formation:

Cerithium.
Tubes of *Gastrochæna.*
Lithodomus.
Lucina tigrina.
L. sp. *L. semireticularia.*
L. quadrisulcata.
Arca biangula.
Dollium sp.
Tellina sp.
T. planata (?).
T. planissima.
Pecten sp.
Cardium sp.
Crassatella sp.
Patella sp.
Bulla sp.
Dendrarea.
Heliastræa.
Meandrina.
Madrepora.

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* "Geology of Barbadoes:" Quar. Jour. Geol. Soc., Lond., 1891, vol. lxvii, pp. 197–250, and 1892, vol. xlviii, pp. 170–226.

In the region of Matanzas the typical beds lie unconformably upon the Miocene. Thus, on the northern side of the Yumuri gorge, between the church and the first lateral ravine, there are about 150 feet of this earthy limestone in beds dipping about 15° north 10° east. It also rises and caps the ridge upon the western side of Matanzas bay, and constitutes much of the case-hardened roadway on the ridge. At the summit of the ridge, crossed by the road from Matansas to Corral Nuevo, the lower part of the Matanzas series is composed of fine, soft, calcareous, mealy powder, with little or no siliceous matter, but it contains water-worn pebbles of the older Tertiary limestones. These materials rest unconformably upon the eroded surfaces of the older Tertiary limestones. This series the writer has denominated *Matanzas formation*, as a distinctive name is necessary. The appellation of "white limestone" has been given to the same formation in the other parts of the West Indies, but it is also used for both Eocene and Miocene deposits. Again, the formation has been confused with coral reefs and other coastal limestones. The section at Matanzas lies unconformably upon fossiliferous Miocene beds and unconformably beneath the modern raised coral reefs of the coast. Much of both the cities of Matanzas and Havana rest upon this Matanzas formation, and the material is used for building purposes.

The Matanzas formation partly filled the Yumuri valley after the erosion following the deposition of the Miocene limestones. Beneath the Montserrat church and resting unconformably upon Eocene strata (for the Miocene had been removed in the excavation of the valley) the marls were found to contain a considerable number of fossils. The species of those determined are modern in types. A few small corals were not determined. The shells were kindly identified by Mr Charles T. Simpson, of the Smithsonian Institution. The marine shells are—

Strombus pugilis, Lin.
Massa vibex (?), Say.
Tectarius muricatus, Lin.
Lucina tigrina, L.
Lucina jamaicensis, Lam'k.
Arca holmesi, K. and St.
Arca americana, Gray.
Perma ephippus (?), Lin.
Venus cancellatus, Lin.
Ostrea virginica, Gm.

A few land shells were also present, some of which had been washed into the sea, in which the other shells were living. They belong to the following species:

Pleurodonta auricoma, Fer.
Helix bonplandi, Lam'k.
Liquus fasciatus, Mul.
Cylindrella lavalleana, Orb.
Macroceramus turricula, Pf.
Strophia incrasata, Reeve.
Chondropoma pfeifferianum, Poey.
Chondropoma dentatum, Say.
Ctenopoma rugulosus, Pf.
Magalomastoma bicolor, G'l'd.
Helicina submarginata (?), Poey.
Helicina zephyrina, Duel.

These shells were found at an elevation of 150 feet above the sea, but the formation occurs to an altitude of perhaps 450 feet.

In the region of Sagua le Grande small remnants of the Matanzas limestone are found resting upon the upturned and eroded surfaces of the older formation, notably the Tertiary strata. This character extends into the interior of Cuba.

In the region of Cienfuegos the Damuji flows through a valley bounded by hills 80 feet high. At Abreus, on that river, the formation is a chalky limestone. Farther up the valley, at the Santa Lucia brook, Mr Mathew found a deposit of buff-colored marl containing remains of olive-bark tree, two mangroves, a fern, a palm, etcetera. However, the formation in this vicinity is very much concealed by tierra negra. West of Damuji the erosion has exposed white pyramids of the formation standing out in strong contrast to the overlying red loams.

In the vicinity of Cienfuegos the Matanzas limestones are most prominent in the plateau ridge which separates the bay from the sea. This plateau is about two miles wide and 100 or 150 feet high and extends for many miles as a coastal terrace. Along the canyon which forms the outlet of the bay the strata dip at 2° or 4° southward. The terrace is shown in figure 6.

FIGURE 6.—*View of Terrace (Matanzas Limestones) at Entrance to Xagua Bay.*
The fort is situated on this terrace, with Trinidad mountains in the distance, viewed from the west. (After Hydrographic Office chart.)

In the region of Trinidad the Matanzas limestones fill the hollows in the surface of the older Tertiary rocks which form the baselevel plain, from 175 to 200 feet above the sea, upon which the city is built. Near the mouth of the San Luiz, which enters the sea three miles from the city, corals aggregated in colonies are common in the limestone ridge which occurs just back of the coast. The Matanzas limestones are not known to exceed a thickness of about 150 feet nor to rise higher in Cuba than 450 feet above the sea. The dip is everywhere at low angles toward the coast.

The Matanzas formation is provisionally included with the Pliocene system, so that it would form its last member if all of the earlier were not wanting in Cuba. This classification is based upon physical considerations, as there is no sharp paleontologic grounds for separating the Pliocene invertebrata from the Pleistocene. The long succession of events following the Matanzas epoch seems to justify the classification, and, further, it is in accord with that which places the Lafayette of the continent at the close of the Pliocene, for the loams of the southern states and the limestones of Cuba occupy the same geomorphic position. On the continent the loams were derived from the enormous supply of the residual soils, but in Cuba there were few islets left above the sea to supply mechanical material to the Matanzas formation.

GEOGRAPHIC FEATURES OF THE PLIOCENE PERIOD.

Already references have been made to the enormous erosion preceding the deposition of the Matanzas limestones, producing a degradation far greater than any since the pre-Cretaceous times. The pre-Matanzas denudation in Cuba is in keeping with that of the pre-Lafayette epoch of the continent, where during the epoch of the great erosion, valleys several miles in width and hundreds of feet in depth were excavated out of the often incoherent formations, ranging from the lower Cretaceous to the upper Miocene strata. In short, the Pliocene period was one of general elevation of the land. This is shown in the Havana valley, where the Tertiary limestones were in many places completely removed before the Matanzas subsidence. The Yumuri valley at Matanzas city illustrates the Pliocene erosion. It was excavated out of Eocene and Miocene limestones to a depth of about 400 feet and a width of three miles, and was afterward partly filled with the Matanzas formation, of which fragments only now remain in the valley (see figure 12, page 92). The work of denudation was not that of a large river, but of the warm tropical rains and rills whose efficiency upon the porous calcareous rocks and sands far exceeds that suspected by one who has not visited the tropics. The amount of denudation is seen in all the large valleys and over the plains of central Cuba, where the Matanzas formation occupies the hollows produced by the earlier Pliocene erosion. From the extent of erosion, evidently removing great ridges, and the structure of the valleys, the conclusion is formed that the duration of high elevation lasted for a long time, and that the altitude was great, probably sufficient to excavate great valleys, but their great depth now submerged was only completed during the next period of erosion. With the following subsidence to 400 feet, more or less, only a few small islands remained. Indeed, from the study of the geomorphy it would appear that the mountains then rose to much more moderate elevations above the sea than at the present time.

PLEISTOCENE HISTORY.

ZAPATA FORMATION.

To the series of red loams and water-worn gravels which succeed the Matanzas the writer has applied the name *Zapata formation.* The name is taken from the extensive low peninsula west of Cienfuegos, which is more or less covered by these mechanical accumulations. The best sections, however, were seen near Trinidad, which may be taken as examples.

The Zapata gravels are water-worn and composed of quartz pebbles from one to two inches in diameter, and in proximity to the Trinidad mountains there are also limestone pebbles associated with the quartz. The thickness of the beds are as much as eight or ten feet, and this deposit is surmounted by red loams varying from one to ten feet in thickness. The loams sometimes predominate and form one undivided bed. In other places laminations of gravel occur in them. Occasionally the whole formation is reduced to a few feet in thickness, but where filling older erosion hollows it may greatly exceed the normal 15 or 20 feet. Where the gravel is not apparent it is often difficult to distinguish the loams from the red and similar appearing soils resulting from the solution of the calcareous matter out of the Tertiary limestones. The formation so closely resembles the Columbia of the southern coastal plains, described by Mr W J McGee,* that their origin is apparently similar. The loams are derived from the residual soils produced by the decomposition of the Tertiary limestones, and most of the gravels are those obtained from the remains of the Miocene formation. The loams are very rich in pellets of iron oxides.

Over the Zapata peninsula the formation is widespread, but owing to the absence of deep ravines the sections are not seen as well as on the higher land near Trinidad, where it occurs up to an elevation of 240 feet.

The Zapata formation rests upon the greatly eroded surfaces of the Matanzas and other earlier formations. Thus it closes the old Xagua bay outlet, to be described later. To this formation apparently belong the sands and gravels up to 10 or 15 feet above the Damuji river entering the Xagua bay. From them Mr Mathew collected the following fossils, all of which are living species:

Murex brevifrons.
Strombus gigas.
Strombus pugilis.
Pyrula melongena.
Nerita texsallata.
Neritinea virginea.
Modulus lenticularis.
Ceritherium versicolor.
Ceritherium vulgatum.
Bulla striata.
Ostrea sp.
Perna obliqua.
Mytilus sp.
Venus cancellata.
Lucina costata.
Lucina tigrina.
Lucina jamaicensis.
Asaphis rugosa.

West of Abreus, and also on the road to Caunau. the soils derived from the Zapata series were found to contain a few fossils of living species.

In the vicinity of Yaguaramas the Zapata peninsula has an elevation of about 100 feet above the sea, and much of the poor surface soil consists

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* The Lafayette Formation: Twelfth Annual Report U. S. Geological Survey, 1892, pp. 347-521.

of the Zapata series. Indeed, some of the low and poor country between Colon and Santo Domingo apparently belongs to this formation.

The resemblance of the gravels to the similar formations in the southern states was noted by Mr Mathew, who saw the likeness to Hilgard's orange sand long before it was differentiated into the several members now known.

Along the Sagua le Grande river, near the city of the same name, resting upon the eroded surfaces of the Matanzas and other Tertiary limestones, there are about 20 feet of impure sand and fine gravel and some layers of pebbles, the whole forming the floor of an extensive plain. In places the layers are horizontal, but in others the beds dip at low angles toward the northeast. These beds appear to be equivalent to those at Cienfuegos.

In the Yumuri valley, west of Matanzas. beds of the gravel were seen at several places, but not at any altitude above 100 feet. These surface deposits also occur at Havana.

GEOGRAPHIC FEATURES OF THE PLEISTOCENE PERIOD.

The old-fashioned method of reading the history of the earth by the succession of the coats of the geologic onion has been followed, but the more important history is that recorded in the breaks and unconformities. When these are studied over large areas we find very broad valleys which have since been filled by the later deposits. In the Havana valley, in the Yumuri valley, and over the plains of central Cuba there is abundant evidence of the enormous degradation to which the island has been subjected, for valleys several miles in width have been excavated since the Matanzas epoch, even to depths of hundreds of feet. Thus the Yumuri valley was reëxcavated during the early Pleistocene elevation to its original or greater size. These valleys continue into the fiords, such as that of Matanzas bay, which have been excavated or reopened since the Matanzas epoch. Other examples of the post-Matanzas erosion are seen in the formation of the bays of Cienfuegos (see figure 10, page 91) and Santiago (see figure 9, page 90). The Cienfuegos harbor was formed between the close of the Matanzas epoch and that of the deposition of the Zapata loams. All of these valleys show the great elevation when the fiords were reopened upon the removal of the Matanzas beds which partly filled them. This elevaton, as shown by the Cuban fiords, alone suggests a late altitude of more than 7,500 feet, as seen in the gulf of Cazones.

In the subsidence from the high altitude there was rest long enough to form the baselevel terraces underlying the Zapata formation at Trinidad, at Matanzas and the plains of the central part of the island. The Zapata subsidence is not known to have exceeded 240 feet below the present level, so that while Cuba was reduced in size it was not so dismembered as in the Matanzas epoch of subsidence.

The elevation of the island succeeding the formation of the Zapata loams and gravels appears to have reached about 200 feet above the present altitude, thus enlarging the Cuban mass. This elevation is inferred by the depth of the canyons which form the outlets of the harbors and extend across the slightly submerged coastal shelves. During this epoch of elevation the amount of erosion was considerable, but it did not exceed more than from one-fifteenth to one-fiftieth of that of the pre-Zapata epoch.

Another subsidence followed the excavation of the outlets of the harbors, carrying the island down to depths necessary to allow the formation of the terraces, and during the subsequent rise the building of the modern coralline reefs; but these two subjects will be considered by themselves.

Terraces, Sea-caves and Rifts.

NORTH COAST OF THE ISLAND.

The most elevated terraces seen are those on Pan de Matanzas, carved out of the Tertiary limestone at an elevation between 1,000 and 1,100 feet above tide, as shown in figures 7 and 8. The summit of the mountain ridge rises to 1,277 feet. At about 700 feet there is another conspicuous terrace, and between 350 and 400 feet the low divide between the peaks corresponds to another water-level. The highest terrace is strongly marked on the northern side of the more western mountain. At the level of the terraces there are also sea-caves and occasional rifts (see *a*, figure 8) or narrow ravines through the ridge which may not be more than a few hundred yards across. The deep depression between the Pan and the western ridge has been broadened by late current action. There are many such rifts, and they mark tide-level as plainly as the terraces record the deserted shores.

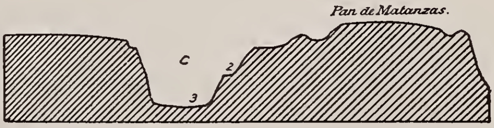

Figure 7.—*Pan de Matanzas from the South.*

Horizontal and vertical scales the same.

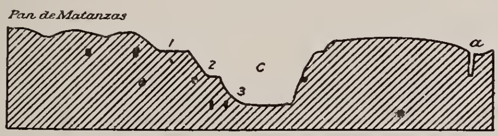

Figure 8.—*Pan de Matanzas from the North.*

Showing terraces and sea-caves (the dark spots) and rifts at *a* and *c*.

On both sides of the ridges there are baselevel plains at about 400 feet, and out of that on the northern side of the Pan, the Yumuri valley was excavated. These baselevel plains are of more recent origin than the Matanzas epoch, but older than the Zapata. At the outlet of Matanzas bay there are four lower terraces inscribed upon the rocks. The one at about 25 feet above tide is the most strongly marked.

From the character of the erosion of the terraces it is probable that all of the terraces except the baselevels are of age more recent than the Zapata epoch, but there is room for possible doubt in the case of the highest terraces.

When rifts such as those described have been seen in northern regions some theorists have considered them evidences of glacial dams, but the Cuban rifts are simply stream-made ravines deepened and widened by sea currents breaking through the depressions during oscillation of the land.

SOUTH COAST OF THE ISLAND.

The baselevel valleys, from 800 feet upward, in the Trinidad mountains, record an elevation as plainly as the other terraces. They have been uplifted so recently that they are not yet penetrated by the growth of the youthful canyons (see figure 2, page 69). The recent terraces have been confused with the frontal plains, such as those at Trinidad and Santiago, which seem to be the product of wave action, modified when at baselevels of erosion. This most important plain has an elevation of about 100 feet at Cienfuegos, 200 to 240 feet at Trinidad and about 350 feet at Santiago (Kimball). This feature antedates the Zapata epoch, as that formation overlaps the plains. However, there are lower terraces. At Trinidad there is a sand terrace at 175 feet and another at 50 to 60 feet, in which there is much gravel, and both of these shorelines are inscribed upon the Zapata series. A lower limestone terrace occurs at an elevation of less than 10 feet in this part of Cuba. Two lower terraces also occur at 175 and 14 feet in the vicinity of Santiago (Kimball). In the region of Baracoa these prominent terraces occur at about 500, 200 to 250 and 30 feet (Crosby). Professor W. O. Crosby also describes baselevel plains at 800 feet, and on Il Yuinqui another at 1,800 feet. The baselevel valleys of the Trinidad mountains, at altitudes from 800 to 1,500 feet, as yet incised to only a moderate distance by canyons, indicate the recent elevation of the mountains.

From these data there appears to have been considerable oscillation during recent geological epochs, with a gentle deformation, raising the southeastern portion of Cuba higher than in the central, but sufficient study of the terraces has not been made for working out their accurate history, such as whether they belong to one or two epochs. That their elevation is recent is shown by the small streams having lately cut canyons everywhere along the coast, too lately to have been transformed into V-shaped valleys.

Besides the epeirogenic and gentle uplifts, the coast ranges of Tertiary rocks show much deformative movements since the end of the Miocene period, and in part much more recent, as shown by the character of the elevated baselevel valleys. From the last subsidence Cuba has not yet recovered, as the canyons forming outlets for the harbors are all far deeper than could be formed at the level of the present outflows. To these subjects reference is again made on page 90.

Modern coralline Limestones or Reefs.

The slightly submerged portions of the Cuban mass noted on page 69 are surmounted by coral reefs and mangrove islands. The most common genera of corals are *Meandrina*, *Astræa* and *Madrepora*. These reefs have been brought above the surface of the sea during the last gentle uplift, which in places appears to be still in progress. These raised reefs occur to an elevation of 25 feet at Matanzas, but on the southern coast they do not rise more than 10 feet, where they form the lowest terrace. The coralline rocks are fine, earthy, granular limestones, very porous, with a white or stained color, and do not show bedding. While the mass is composed of corals, there are very few or no mollusks or echinoderms in them. These raised reefs have a structure quite unlike the Matanzas limestones, which contain shells and only occasional masses of coral where fossils are found. The reefs form only narrow fringes, varying from a few to perhaps 200 yards wide. In front of the Trinidad mountains they are absent, but the terrace is there present.

Some Erosion Features.

Very large, rounded blocks, having the appearance of erratics, occur on the shores of Xagua fiord, but they are composed of the harder rocks of the adjacent shores, rounded by the action of the waves, and stranded upon the waterline. In many places north of Pan de Matanzas and in other localities there are boulders of Tertiary limestone, of two feet or more in diameter, resting upon the residual soil which conceals the mother rock, but they appear to be the residual masses of the more durable materials. Opposite Havana the decaying diorite gives rise to rounded boulders of decomposition which resemble erratics.

In the Yumuri and Trinidad valleys and elsewhere there are rounded domes or hillocks from 100 to 300 feet high with the outlines of northern drumlins. This external form is evidently the character assumed by the incoherent strata subjected to atmospheric influences, irrespective of latitude. Again, these hillocks form chains, with the outlines of the osar, arising from the unequal erosion.

Rivers deserting their old courses and cutting out new channels is another imitative feature, which will be noticed under the head of harbors.

Rifts across ridges, made by waves opening narrow valleys, have already been referred to on page 87.

Rock-basins like others of the north, and produced by modern faulting, also occur. They are illustrated on page 92.

Harbors.

A few harbors such as that of Matanzas are simply the heads of deep bays which extend out into fiords. Others are the products of corals building reefs leaving shallow lagoons. A few are closed by sandbars forming hooks such as that of Casilda, the port of Trinidad. There is another class of harbors, however, which are very common throughout the West Indies; they are land valleys, often of considerable magnitude, depressed below the water-level and closed by rocky barriers. While their breadths may be great, their outlets are through narrow canyons of recent formations. Without carrying the generalizations beyond those harbors seen, the writer will offer one notable example for future study.

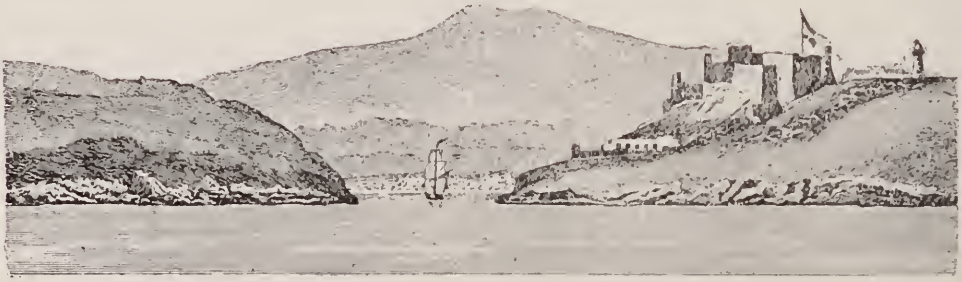

FIGURE 9.—*Bay and Valley at Santiago.*

The narrow and deep canyon which forms the egress of the broad bay and valley is 700 feet wide and 350 feet deep to waterline. (After Hydrographic Office chart.)

Xagua bay, or the harbor of Cienfuegos, is the united continuation of several smaller valleys depressed below the sealevel. The bay is about 12 miles long and from three to four miles wide, while the canyon forming the outlet is only 1,200 feet wide at the narrowest point. The bay increases in depth from a few feet to about 120 feet near its egress, but the canyon becomes a fiord 168 feet deep (see figure 11). The southwestern boundary of the valley and also the plateau separating the bay from the sea are composed of Matanzas limestones which rise to 100 or 150 feet above tide. Upon the northeastern side of the bay the land rises gradually and is underlaid by Miocene clastic deposits. This valley (now the bay) was excavated by atmospheric erosion after the Matanzas epoch or during the high Pleistocene elevation already described.

The outlet of the valley continued to the deep outer fiord of the gulf of Cazones by way of the depression north of the now closing barrier shown on the map (see figure 10), and in a direct line eastward of the figure where the seacoast sets back and forms a bay into which the Arimao river empties. Indeed, at floods there is a low connection by which small boats can still pass from the bay to the Arimao, which Mr Mathew states was a path of retreat for the pirates of two centuries ago, when the passage appears to have been deeper. This continuation of the Xagua valley was closed and is now occupied, according to Mr James Fowler, by accumulations of the red Zapata loams.

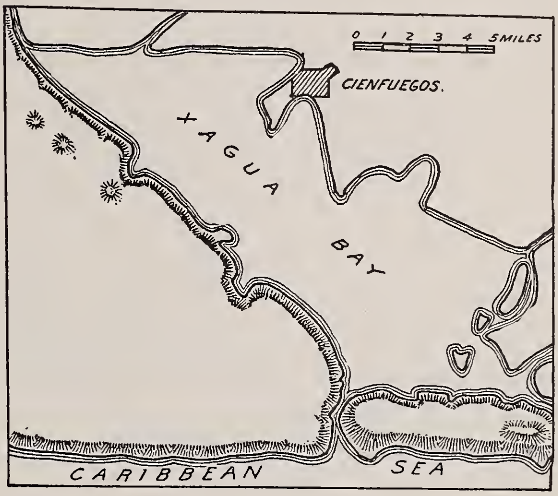

FIGURE 10.—*Xagua Bay.*

There is a closed depression extending from the southeastern end of the bay to the Arimao river and bay.

From the Zapata submergence the surface of the land in rising permitted the waters to break across the plateau at the present outlet of the bay, and with the continued elevation the canyon was formed; but from its depth there is the evidence that the altitude reached 150 or 200 feet above the present level—a feature noticed at the outlet of many of the bays and the rivers which everywhere along the coast have cut out just such canyons as that of Xagua before entering the sea. The excavation of the outlet of the bay represents the post-Zapata erosion. Here the canyon is about two miles long, 1,200 feet and more in breadth, with a total depth of nearly 300 feet.

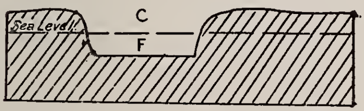

FIGURE 11.—*Cross-section of Outlet of Xagua Bay.*

Showing the canyon and fiord at the mouth of the bay. Horizontal and vertical scale the same.

YUMURI ROCK-BASIN.

On the northern side of Pan de Matanzas there is an old baselevel plain, about 400 feet above the sea, having a breadth of some five miles. Out of this plain the Yumuri valley is excavated. The length of the valley is about six miles, with a breadth of about two and a half or three miles. Its depth is about 400 feet. The lower portion of the valley is a plain, showing flooding, as if it had been a recent lake or bay. The upper part of the valley rises in the form of an amphitheater made by rain-washes. Closing this valley and separating it from the deep Matanzas fiord there is a range of hills about a mile across their base. This eastern end of Yumuri valley is divided into two lobes by an insular hill, shown on the map. The elevation of this barrier ridge is from 250 to 400 feet, and its longitudinal section is shown in broken shading in figure 13, while the form of the valley is seen bounded by solid shading. The remarkable feature of the outlet is its smallness, for it is a canyon with vertical walls, the extreme height of which is 250 feet, and breadth 300 feet, but the ridge slopes upward gently on both sides, producing a shallow depression in the barrier closing the valley (see figure 13). There is a second shallow depression, indicated by *b*, figure 13, the two depressions (*a* and *b*) corresponding to the two lobes of the valley.

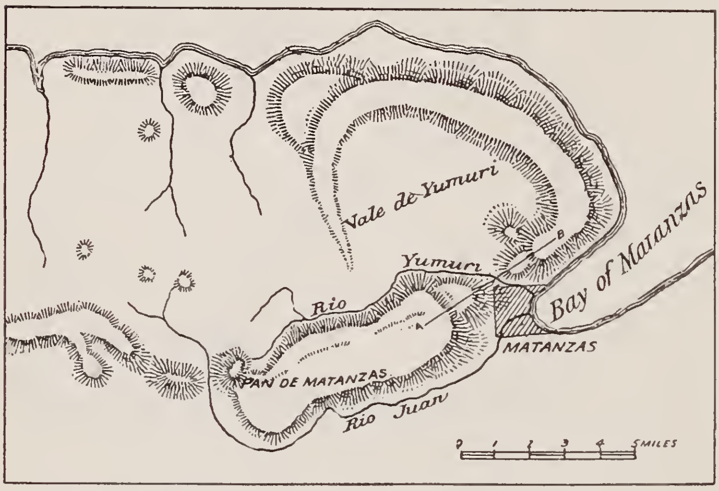

FIGURE 12.—*Map of Yumuri Valley.*

A B = position of section shown in figure 13.

The contrast between the modern canyon, forming the only outlet of the valley, and the magnitude and the age of the valley are most striking, and at first would appear difficult of explanation by any cause that could be demonstrated, but in examining the canyon it was found that the older Tertiary and late Pliocene (Matanzas) formations were involved in the most recent disturbances, and that there had been a fault near the inner side of the barrier separating the valley from the outer bay (see figure 4, page 76). This fault furnishes an adequate explanation for the basin, and its vertical elevation was from 250 to 400 feet, or the amount of elevation of the hollows (*a* and *b*, figure 13), which were the continuations of the two lobes of Yumuri valley, as shown in figure 12.

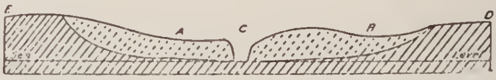

FIGURE 13.—*Longitudinal Section of Ridge closing Yumuri Valley.*

C = canyon; *A* and *B* = former extensions of valley.

The character of the valley being now known, the remaining question was the date of the faulting. That it was long after the Pliocene times is shown by the involved Matanzas limestones, which were eroded from the valley before the elevation of the closing barrier. This movement turned the valley into a lake-basin until it could be drained by making its new outlet. The time of the formation of the canyon was the same as that of all the gorges along the coast, or, as has been shown in the case of Xagua bay, since the Zapata epoch; that is, since middle Pleistocene days.

CAVERNS.

The limestones of Cuba are frequently very much perforated by caverns. The rocks are often completely honeycombed upon their surfaces by rains alone, as at Trinidad. Some strata are more cavernous than others, but none are exempt from the solvent powers of the tropical rains. Some of the caves descend below sealevel. Many of the caves are large, and some of them have formed retreats for animals, and even man, as some flints and pottery were found by the writer in a cave at about 350 feet above the sea at Trinidad. There were also a number of shells which had been washed into the red, cave earth (not derived from the walls of caverns) during some recent subsidence, or else have been carried there for human food, which latter is suggested, as the shells are mostly broken. The species were kindly determined for me by Mr Charles T. Simpson

Melongena melongena, Lin.
Livona pica, Gm.
Strombus gigas, Lin.
Arca auricula, Lam'k.
Arca noae, Lin.
Lucina jamaicensis, Lam'k.
Mytilus hamatus, Say.

In the same cave Mr Frank M. Chapman found bones of an extinct *Capromys* (*Hutia*). The cave is now tenanted by bats.

SUMMARY.

This paper treats of the geological history of Cuba primarily from the geomorphic standpoint, as recorded in the great valleys of erosion during the Pliocene and Pleistocene periods, and their extension into the deep fiords. These physical changes are summarized in the form of the following table. While the paper was mostly written as a preface to the "Reconstruction of the Antillian Continent," it was not ready for publication until afterwards, hence the comparison between the geology of Cuba and that of other islands of the West Indies, and also the character of the fauna of the island, have been considered in the paper already named.

*Table of the Geological Succession in Cuba.**

Systems.	Formations and their Movements.
Modern	Modern coral terraces; elevation, 10 to 30 feet.
	Formation of coralline limestones; submergence, 10 to 30 feet.
	Terraces: *A*. Lower series; elevation from 100 to 300 feet or more. *B*. Higher series, which may belong to the same episode; elevation from 100 to 1,100 feet.
	Submergence during formation of terraces, 100 to 1,100 feet.
Pleistocene	Post-Zapata elevation, with the erosion of the coastal canyons and outlets of harbors, etcetera; elevation, 100 to 200 feet or more in the mountains.
	Zapata formation (red loams and gravels); subsidence, 100 to 240 feet.
	Pre-Zapata depression, with the formation of baselevel plains, 100 to 400 feet.
	Post-Matanzas elevation; an epoch of enormous erosion; altitude from evidence within the insular mass of Cuba, over 7,500 feet; general physical disturbances slight, but with the mountains elevated higher than in the earlier period.
Pliocene	Matanzas formation (marly limestones); subsidence, 200 to 400 feet.
	The Pliocene or post-Miocene elevation; an epoch of enormous erosion; altitude did not equal that of the post-Matanzas, which last, during the erosion of the Matanzas limestones from the post-Miocene valley, removed the Matanzas formation to below sealevel; general physical disturbances during early stage, with elevation of mountains.
Miocene and Eocene.	Series separated only in some localities; materials mostly limestones and marls, but sands and conglomerates occur in part of the Miocene; subsidence during formation of limestones from 750 to 2,300 feet, with intervening oscillations. In or before the Miocene period there appears to have been local depressions to abysmal depths during the accumulation of radiolarian earths.
	Post-Cretaceous elevation; general altitude moderate; physical disturbances general, with formations of low mountain chains.
Cretaceous	The formation composed of sandstones and limestones; subsidence widespread.
	Pre-Cretaceous (?) elevation and low plains.
	Pre-Cretaceous (?) igneous rocks and metamorphic formations.

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* Altitudes refer to elevation above or depressions below sealevel.

SEPTEMBER, 1894.

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SYENITE-GNEISS (LEOPARD ROCK) FROM THE APATITE REGION OF OTTAWA COUNTY, CANADA*

BY C. H. GORDON

(Presented before the Society August 28, 1895)

CONTENTS

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*Condensation of thesis presented for degree of Doctor of Philosophy, University of Chicago, June 13, 1895.

The author is indebted to Dr A. R. C. Selwyn and his associates on the Canadian Geological Survey and to Mr A. P. Twidale, superintendent of the High Rock phosphate mine, for numerous courtesies and favors. The analyses were made by Professor William Hoskins, of the Chicago Academy of Sciences. Especial acknowledgments are made to Professor J. P. Iddings for his keen, critical analysis and painstaking assistance. Without his aid the paper would lack much of any value it may possess.

INTRODUCTION.

GENERAL DESCRIPTION OF THE REGION.

The apatite region of Ottawa county comprises the area included between the lower portions of the Du Lievre and Gatineau rivers. The chief mining districts occur in Portland and Templeton townships, but deposits of greater or less extent are found over nearly the whole of the area.

The region lies upon the southern flank of the Laurentian axis, and is characterized in large part by a somewhat rugged topography. For some distance north of the Ottawa river, the surface is comparatively level, but this feature gradually gives place to hills which rise to a height of from 500 to 700 feet above the level of the adjacent rivers. The hills are covered with a meager soil, and the forest growth, originally limited, has been largely swept away by fires. The region is drained chiefly by the two rivers mentioned above, which flow southward into the Ottawa river. These streams are of considerable size, have swift currents, and rapids frequently occur. Waterfalls also constitute a picturesque feature of these streams. High falls, on the Du Lievre, has a descent of about 100 feet.

The country between the streams is dotted with numerous lakes, which drain through small streams with tortuous courses into the Du Lievre or the Gatineau, or southward into the Ottawa. These lakes are extremely irregular in shape, with sharply sinuous shorelines, and often contain small islands.

GEOLOGY OF THE REGION.

Character and classification of the rocks.—In order to arrive at a proper understanding of the nature and occurrence of the ellipsoidal syenite-gneiss or leopard rock, it is necessary to introduce a brief description of the geology of the region. The facts upon which this description is based have been obtained chiefly from the reports of the Canadian Geological and Natural History Survey.*

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* We are indebted chiefly to the reports of Vennor and Harrington, and to Professor F. D. Adams' account of the typical Laurentian area in the Jonrnal of Geology, vol. i, No. 4, 1893, pp. 325–340. The map here given was taken from that accompanying H. G. Vennor's report in the Annual Report for 1878.

In its geological structure the region consists of alternating bands of gneiss, crystalline limestones and pyroxenic rocks, in which are interstratified a number of zones of quartzites, rust-colored rock or fahlbands, and several horizons of magnetic iron ore. These rocks all belong to the Grenville series, the uppermost of the two main divisions into which the Laurentian system is now quite generally divided.

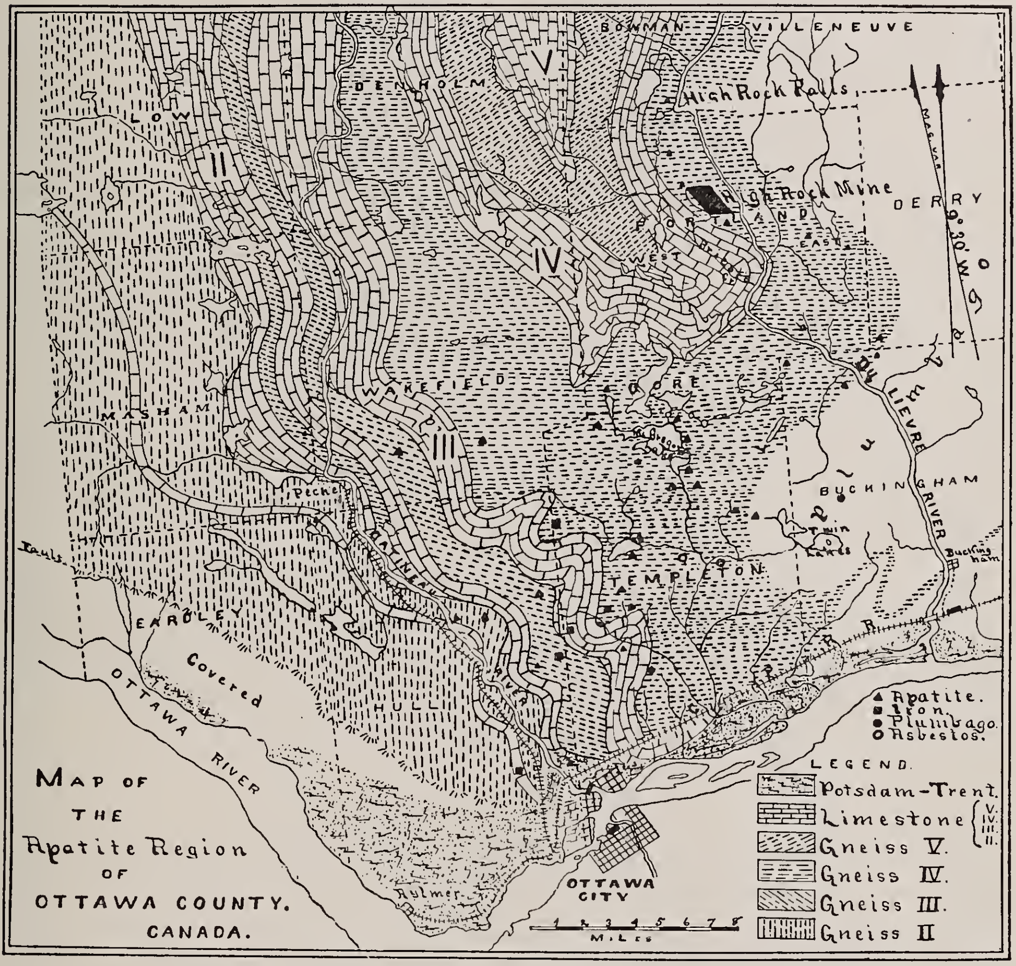

FIGURE 1.—*The Apatite Region of Ottawa County, Canada.*

The Grenville series includes rocks of very different petrographical development and of great variability in mineralogic composition. "In it are found all the mineral deposits of economic value—apatite, iron ore, asbestos, etcetera—which occur in the Laurentian."*

Apatite is found quite generally throughout the series, but the principal workable deposits occur in a belt (see IV, figure 1) of rust-colored

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*Journal of Geology, vol. i, No. 4, p. 327.

gneisses and pyroxenic and feldspar rocks above the Gatineau limestone band (III).

As shown on the map, in the region between the Gatineau and Du Lievre rivers the rocks are arranged in the form of a great synclinal, with Big lake marking approximately the location of the axis. On passing eastward from the west line of Ottawa county, therefore, we pass over the different belts in ascending order until we reach the east line of Denham township.

Lithological characters.—The gneisses interstratified with the limestones vary much in character, but the predominating variety consists of a more or less reddish orthoclase and grayish white quartz with little or no mica and sometimes with garnets. It is usually coarse or granitoid in structure and the bedding often obscure, though in places it contains numerous beds or layers of quartzite from half an inch to a foot in thickness, which render the strike of the rock plainly visible. In some cases the mica is abundant and the gneiss then assumes a marked foliated character. The micaceous gneisses are sometimes garnetiferous and occasionally exhibit the texture of the so-called augen-gneiss.

Quartzites of considerable thickness occur now and then. They are often white and glassy and in places contain a little orthoclase. These strata are frequently traversed by dolerite dikes, some of which are of considerable thickness.

The pyroxenic rocks associated with the apatite, and by Hunt* called pyroxenites, vary considerably in their characters. Sometimes they consist almost exclusively of pyroxene, though commonly quartz and orthoclase are present. Mica and apatite are of frequent occurrence, and occasionally minute garnets may be seen.

HIGH ROCK DISTRICT.

General description.—High Rock mine, the locality at which the material for this study was obtained, is located on a series of connected hills situated on the right bank of the Du Lievre river, about 21 miles above Buckingham. The openings cover in all about 600 acres on the tops of the hills which extend to a height of 700 feet above the level of the river. They are reached from the river by a tramway two miles long following the natural slope of the hill. The series of hills trend in a direction south 30° east (magnetic). The openings are all in one wide belt of pyroxenic rock having a strike in the same direction. The main opening is number 11, the entrance to which is on the west side of the hill about 180 feet below the summit. The vein in which this pit is opened has been worked at several places along the side of the hill. Other veins

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* Geology of Canada, 1866, p. 185. Chemical and Geological Essays, p. 208.

parallel with this occur along the top of the ridge and have been worked at various points. In all some 35 or 40 openings have been made on this property.

Geological structure.—The hills are made up of quartzite, pyroxenite, and gneiss in belts whose direction corresponds with that of the ridge. The apatite occurs in veins or pockets in the pyroxenite. The quartzite occurs in beds standing in a nearly vertical position and with strike parallel to the general direction of the ridge.

The pyroxenite is not distinctly banded, though occasionally parallel lines, which have sometimes been taken to represent lines of stratification, can be traced through it.

Stratified and massive gneisses are reported * as often seen bordering the hills in the apatite region, but they were not made the subject of study at High Rock.

The rocks all dip at high angles (nearly vertical), and are cut in various directions by small dikes.

At several places on the hill bosses of feldspar rock appear protruding through the quartzites and pyroxenites, and expanding at the surface. An instance of this is seen near the summit in front of the office. The feldspar is coarsely crystallized, of a lilac color, and is associated with a considerable amount of augite.

In most of the openings, the apatite is associated with a reticulated feldspar rock, consisting of lumps of coarse feldspar (and a variable amount of quartz), separated from each other by thin anastomosing layers of green augite and a small amount of fine grained feldspar. This rock, which it is the chief purpose of this paper to discuss, is closely associated with the coarse feldspathic rock above mentioned, and evidently belongs to the same rock body. In places it has a distinctly striped gneissoid appearance. In general it is composed chiefly of an alkali feldspar and augite, with a comparatively small amount of quartz, thus presenting the mineral composition of an augite-syenite. As the rock in all its phases shows more or less evidence of dynamic action, it is properly to be regarded as a gneiss, and may therefore be designated as an augite-syenite-gneiss.

SUBDIVISIONS OF THE SYENITE-GNEISS.

The term syenite-gneiss is here used to include a peculiar assemblage of rocks occurring at High Rock and neighboring mines, among which is the so-called "leopard rock" or "concretionary veinstone" of the Canadian geologists. The rock presents three distinct phases, which for con-

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* Penrose: Bulletin 46, U. S. Geol. Survey, p. 26.

venience may be treated separately, though they belong to the same rock mass and grade into each other almost imperceptibly. They are—

Coarse grained syenite-gneiss.
Ellipsoidal syenite-gneiss (leopard rock).
Streaked syenite-gneiss.

Geological Occurrence of the Rock.

The rock here described occurs in the form of dikes, sometimes cutting across the strike of the inclosing rocks and sometimes intercalated in them. In one form or another it is found at nearly all the apatite openings examined.

At the top of the hills at High Rock, about 20 rods southeast of the office, the exposed surface consists of a belt of pyroxenite inclosed in quartzite, with a strike of south 30° east (magnetic). At one point there is a slight linear depression covered with soil transverse to the strike of the rock, which evidently represents a fault. On the south side of this depression the beds of quartzite and intercalated pyroxenite have been shifted about two feet to the east. On the north side both pyroxenite and quartzite are cut by a dike of coarse grained syenite in a direction south 20° east (magnetic). After passing the supposed fault-line the dike

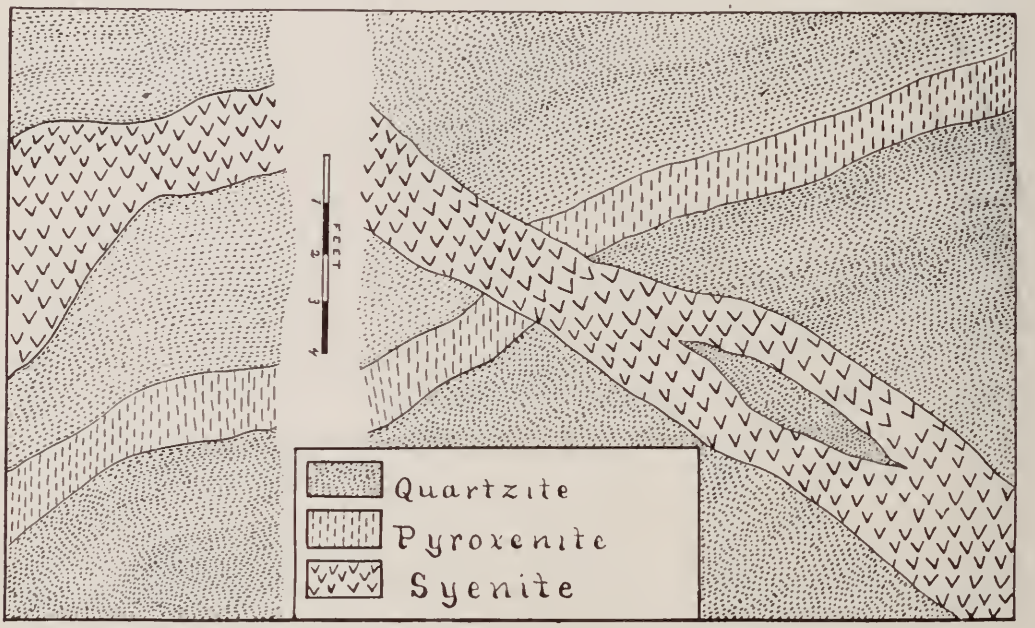

Figure 2.—*Dike of coarse Syenite-gneiss cutting Quartzite and Pyroxenite.*

A mass of the quartzite is inclosed in the syenite. The pyroxenite appears as a dike intercalated in the quartzite.

bears easterly, parallel with the bedding of the quartzite. These relations are shown in the accompanying sketch.

The dike is about a foot wide, and consists chiefly of coarsely crystallized dark grayish or purplish feldspar (microcline), with grains and aggregates of augite and occasional patches of quartz. The grain is quite uniform, except for a thickness of about one centimeter next the walls, which is of a finer grain (number 132). At one point a fragment of the quartzite is inclosed in the syenite. At an apatite opening southeast of this, in the line of strike, the syenite is seen cutting the pyroxenite, as shown in relief in figure 3. The pyroxenite has been broken up, and the different parts intricately involved in the intrusive mass. At this exposure the different phases shown by the syenitic rock are seen grading into each other. In some parts the intruding rock is of a coarse grained character, while in other places it shows the ellipsoidal structure, grading finally into the striped gneissoid rock. At one point in the wall of the pit a large mass of the pyroxenite (*A*, figure 3) is in contact on one

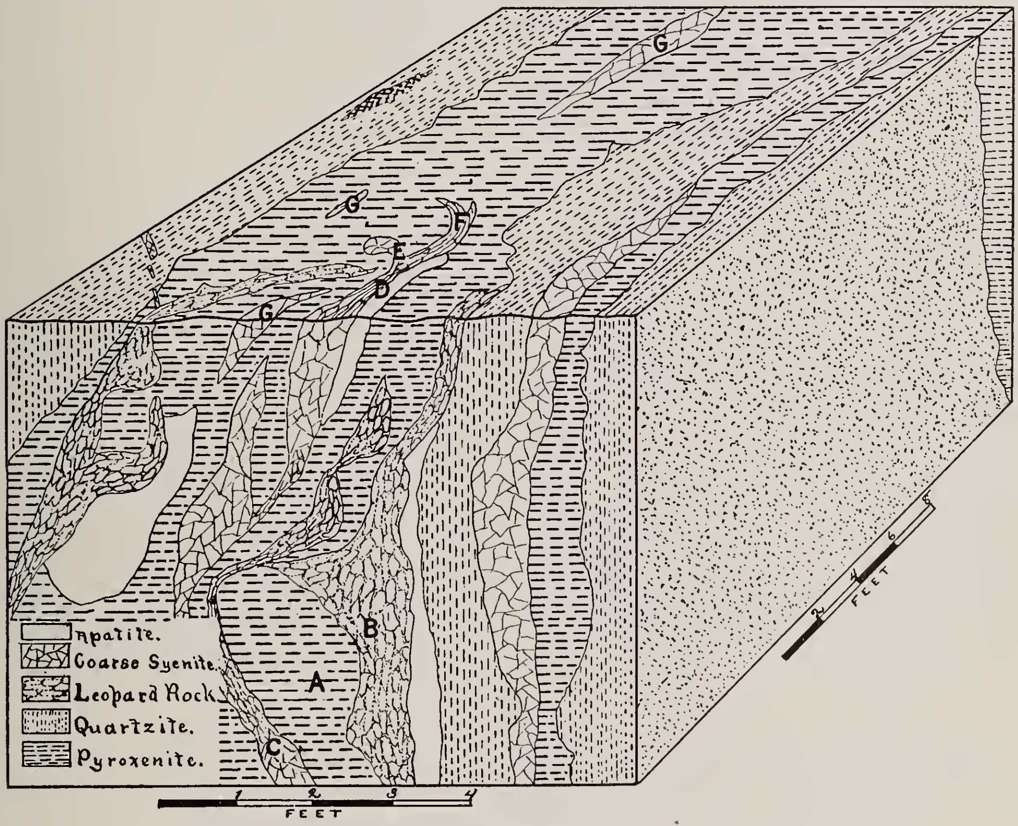

FIGURE 3.—*Intrusion of Syenite in Pyroxenite and Quartzite.*

The locality is at an apatite pit on the hill, about 30 rods southeast of the office. The front face indicates the relations as shown in the wall of the pit, while the top represents the surface exposure.

side with the coarse grained variety (*C*), while on the other (*B*) there is an excellent development of the ellipsoidal structure, with the longer axes of the ellipsoids arranged approximately parallel to the adjacent boundaries of the pyroxenite. The latter at the point marked *A* shows an interlamination with apatite such as has been frequently noted in the apatite regions.*

The surface exposure shows one branch (*D–F*) of the syenite intrusion narrowed and curving. At *D* the ellipsoids have become so flattened and attenuated that in transverse section they appear as parallel bands of reddish white feldspar alternating with thin stripes of augite. At *F*, however, the ellipsoidal structure again appears with sharp little trenches surrounding the feldspathic ellipsoids, due to the weathering of the interstitial augite layers (number 139). At *E* a branch is given off, which consists of the coarse grained syenite rock, with no indication of ellipsoidal or banded structure. Other portions of the syenite rock make their appearance at the surface here and there as lenses (*G*) in the pyroxenite.

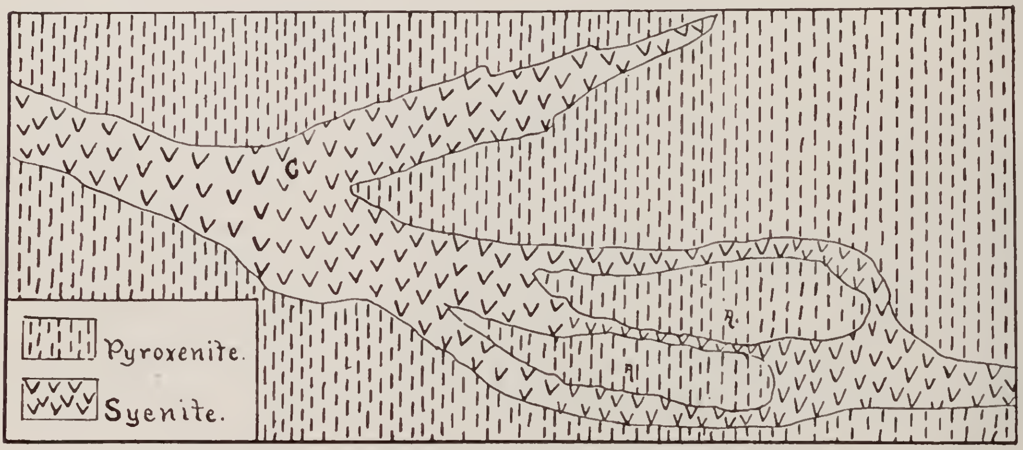

FIGURE 4.—*Dike of coarse Syenite-gneiss cutting Pyroxenite and inclosing Portions* (*A*) *of the latter.*

On the brow of the hill above pit number 11 the pyroxenite is cut by a dike of syenite, a foot or more wide, extending from north 10° west to south 10° east.

The dike dips into the hill at a slight angle with the vertical, and at one point gives off a branch (*C*), which soon wedges out in the pyroxenite. Fragments of the pyroxenite are inclosed in the syenite, as shown

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* W. Boyd Dawkins: Proc. Manchester Geol. Soc., 1884.

NOTE.—The rocks referred to here are represented in the collection by the following numbers

A = numbers 109, 110, pyroxenite.
B = number 138, ellipsoidal syenite-gneiss.
C = " 133, coarse syenite-gneiss.
D = number 139, ellipsoidal gneiss, weathered.
E = " 140, streaked syenite-gneiss.

at *A*. The intruded rock (number 164) is medium to coarse grained, but shows a finer texture in the narrow passage between the inclosed masses of pyroxenite.

At number 11 opening the ellipsoidal or leopard rock occurs in abundance, and constitutes a large part of the wall in places. At one point in the face of the wall a crystal of apatite, six inches or more in diameter, was seen inclosed in the leopard rock, with the ellipsoidal masses disposed in a concentric manner about it. Examples showing the same relations between more or less crushed apatite and the leopard rock were frequent in the refuse of the dumps, but the presence of crystallographic form is exceptional.

At various places on the hill dome-like masses of the coarse grained syenite rock appear as local enlargements of the dike. One of these near the office shows fragments of pyroxenite scattered through the intrusive mass.

These observations, which may be duplicated many times in the vicinity, are sufficient to demonstrate—

1. That the coarse grained syenitic rock, the leopard rock and the streaked gneiss belong to the same rock-body; and,
2. That this body represents an intrusion of syenite later than that of the pyroxenite.

An interesting feature of these syenitic rocks is their remarkably fresh condition. This appearance, which is prominently characteristic of the rock in the hand specimen, is also shown in the thin section, where very little evidence of decomposition is to be observed. Epidote and chlorite, generally common as decomposition products, are rare in these rocks.

Megascopical Characters.

COARSE SYENITE-GNEISS.

The first of the syenite-gneisses consists of a very coarse grained mixture of microcline and monoclinic pyroxene chiefly, with a variable amount of quartz. The rock is divided into irregular angular blocks, the largest being one or two inches across, separated by thin anastomosing sheets of granular feldspar, augite and quartz. These interstitial areas are sometimes thick enough to be readily traceable in the hand specimen. Many, however, are scarcely or not at all recognizable megascopically, but are brought out with distinctness under the microscope.

The microcline is of a dark gray, often purplish color, crystallized in large individuals, frequently from one to two inches in diameter. The larger cleavage faces show a slight undulatory surface, with variable reflection and bright pearly sheen.

An analysis of the microline by William Hoskins, of Chicago, gave the following results:

SiO_2	64.54
Al_2O_3	20.55
Fe_2O_3	.45
CaO	.99
MgO	trace.
Na_2O	1.62
K_2O	10.78
BaO	.32
Loss by ignition	.49
	99.74

The pyroxene is of a dark green color, and occurs both in well formed prisms and as irregular aggregates of considerable size. The prisms are long and slender, and occur chiefly inclosed in the microcline, though they are associated sometimes with the quartz in the granular areas. In the latter case, however, they are usually shorter and sometimes show evidence of breaking. The prisms are elongated in the direction of the vertical axis and have a very nearly equal development of the faces $\infty P \bar{\infty}$ (100), $\infty P \breve{\infty}$ (010), P (110). The pyroxene is more abundant in places, forming aggregates, inclosing a varying amount of feldspar, pyrites, and titanite. In these areas the pyroxene is coarsely crystallized and of a lighter green than the idiomorphic individuals.

An analysis of the crystals inclosed in the microcline by Mr Hoskins gave the following results:

SiO_2	49.79*
Al_2O_3	2.93
FeO	18.95
CaO	21.76
MgO	5.60
Na_2O	.61
K_2O	.36
	100.00

The analysis shows a high percentage of iron, while alumina and magnesium are correspondingly low. Taken in connection with its physical characters, the analysis seems to indicate an augite closely allied to diallage.

Quartz occurs chiefly in nests and strings, associated with the interstitial granular areas. Titanite is present as grains disseminated through the rock, but is more abundant along the granular areas. A fine grained

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*The per cent of silica was rendered doubtfully low by an accident, and is put in by difference.

form of this variety is represented in the collection by two specimens (numbers 128, 129), which are quite uniformly granular and without a distinct gneissic structure. The chief constituents, feldspar and augite, are more or less uniformly distributed.

ELLIPSOIDAL SYENITE-GNEISS.

In the second phase the rock consists of irregularly ellipsoidal or ovoid masses of feldspar, with more or less quartz, separated by narrow anastomosing partitions of green interstitial material, in which there is sometimes observed a slight schistosity parallel to the surface of the masses they inclose. This is sometimes apparent also in the tendency of the rock to cleave at the contact between the ovoid lumps and the interstitial material.

The ellipsoidal masses are usually more or less elongated and arranged uniformly, with the longer axes lying in the same direction. They are of all sizes up to two or three inches in diameter in cross-section, and several inches long. The grain of the feldspathic lumps is coarse in the more spheroidal forms, but becomes finer as the masses become more and more flattened and elongated. They are composed chiefly of feldspar, with a varying amount of quartz and disseminated grains of titanite, augite and apatite. Larger grains of feldspar often appear in the more flattened forms, inclosed in the finer grained mixture. The interstitial material is of finer texture than these ellipsoidal masses, and seems to be composed chiefly of pyroxene, along with finely granular feldspar and some quartz. The interstitial material sometimes has the appearance of two layers of pyroxene separated by a thin light colored lamina feldspathic in character. In many cases these are seen to represent the wedging out of the ellipsoidal feldspathic masses. Often the thin seam of feldspathic material between two adjoining ellipsoids is found to be directly connected with the small masses of feldspar occupying the angular space between three or more ellipsoids. Sometimes the lumps are flattened to thin lenticular or disk-like forms, which may be bent or folded so as to partially enwrap or inclose adjoining lumps. As these flattened lumps become thin they wrap about the larger ellipsoids, so that when the rock breaks across them the constituents appear to have a concentric arrangement. In some cases, however, the concentric arrangement could not be traced directly into connection with the flattening of the feldspathic masses. The interstitial bands are composed chiefly of dark green pyroxene, in grains often elongated parallel to the vertical axis, along with more or less finely granular feldspar. The pyroxene grains often lie with their longer axes transverse to the pyroxene band, with their ends projecting into the feldspathic areas, thus presenting somewhat the appearance of a radiate structure. Usually a thin layer of the feldspar adjoining the pyroxene bands is finer grained than the main part of the lump, but in some cases one or more large grains of microcline will appear to lie directly against the pyroxene band. On close inspection, however, they will be found to be separated by a very thin layer of fine grained feldspar. A mass of the rock will sometimes show a thin seam of the light colored constituent cutting across both pyroxene layers and feldspathic ellipsoids. In may be traced across the latter by its lighter color and finer grain. In specimen 150 a seam of this character cuts entirely through the block, and apparently represents a fracture which has been recemented by subsequent crystallization.

The interstitial filling weathers more readily than the ovoid masses, leaving sharp little trenches surrounding these on exposed surfaces.

Beginning with a somewhat flattened ellipsoidal form, the feldspathic masses become more and more flattened in one direction and extended in a direction normal to it. With this flattening of the ellipsoids, the pyroxene shells become thinner and arrange themselves more and more in parallel bands until the ellipsoidal structure is more or less completely lost, and in its place there occurs a striped gneissoid rock constituting the third phase. On cross-fracture the pyroxene layers of the latter are seen to coalesce, clearly indicating its relationship to the ellipsoidal rock. Where the rock incloses large crystals or masses of apatite the ellipsoidal lumps arrange themselves more or less concentrically about the inclosure, a feature which is characteristic also of the bands of pyroxene and feldspar in the succeeding phase. This is well shown in specimens 137, 146, 148, 154 and 158.

STREAKED SYENITE-GNEISS.

As the ovoid masses become more flattened and disk-like the augite layers arrange themselves in parallel bands, alternating with the thicker feldspathic layers. Moreover, there is a marked diminution in the size of the grains, while quartz becomes relatively more abundant. Here and there areas appear which are coarser grained, and in these the pyroxene is less abundant, and is disseminated in grains and small masses instead of being aggregated into layers. There is also observed occasionally in the fine grained gneissoid rock large grains of feldspar, which sometimes inclose grains of pyroxene. The masses of apatite inclosed in the rock vary in size from a few inches to a foot or more across, and around them the bands of pyroxene and feldspar curve concentrically. The apatite is crushed in part or wholly to a granular, saccharoidal condition. Number 145 shows a portion of such an apatite mass in connection with the adjoining rock. The latter is rather fine grained and is striped with pyroxene and feldspar for a space of 10 centimeters from the apatite, beyond which it is coarser grained and without the streaks of augite. In this part the pyroxene is much diminished in amount and occurs only in small, scattering aggregates and grains. Immediately next to the apatite is a layer of feldspar, from ½ to 1 centimeter thick, and much coarser in grain than the succeeding bands. Moreover, the apatite mass is intersected by several thin veins of feldspar and quartz, continuous with that of the surrounding layer. These seams vary in width from 2 millimeters to 5 millimeters, and vary proportionally in the size of grain. At one point a grain of feldspar occupies the full width of the seam. The apatite is granulated on the outer surface of the mass, while the remaining portion is irregularly fissured and broken, though not completely crushed.

In number 155 the layers are sharply plicated, and the augite and feldspathic constituents intermingle to a greater extent than in those with straight layers, thus partially obscuring the banding.

MICROSCOPICAL DESCRIPTION.

COARSE SYENITE-GNEISS.

Specimen number 127 (129) consists of coarsely crystallized microcline and a monoclinic pyroxene, with quartz, titanite, apatite and pyrite as accessory constituents. Occasionally a small prism of tourmaline is observed.

The microcline is of a dark gray color and occurs in large grains inclosing numerous well formed prisms of augite, usually long and slender.

The rock is intersected in various directions by granular bands which separate the mass into angular lumps of various sizes. These interstitial bands are usually thin, but become somewhat thicker in places, and consist chiefly of finely granular feldspar, quartz and augite. The quartz appears usually in connection with these granular bands, sometimes in aggregates of considerable size. These interstitial seams, therefore, constitute a rather obscure network of fine grained feldspar, pyroxene and quartz, inclosing various masses of coarse microcline and augite. The augite in the quartz areas occurs both as grains and prisms. The latter, however, are usually shorter than those inclosed in the microcline, and present less well defined crystallographic outlines. Sometimes two short prisms of the same size may be seen lying end to end, but not quite in the same straight line. The idiomorphic individuals are elongated in the direction of the vertical axis, and show a very nearly equal development of the faces $\infty P \overset{|}{\bar{\infty}}$ (100), $\infty P \grave{\infty}$ (010), P (110).

Section 129, cut transverse to the granular band seen in the hand specimen, shows this area to be made up of small angular and rounded grains of microcline, between which in places there is a small amount of feldspar similar to that forming the microperthetic intergrowth observed in the large microcline grains, and which is probably albite. Quartz appears in irregular elongated grains here and there along the granular areas. It has crystallized sharply against the adjoining constituents, fitting closely into their sinuous outlines. Some grains are long and irregular in shape, while others which appear similar are resolved in polarized light into two or more grains having slightly different orientations. Rows of fluid inclusions frequently extend uninterruptedly from one quartz grain to another, while in a few instances they were observed in direct continuity with similar lines of inclusions in the adjoining microcline plates.

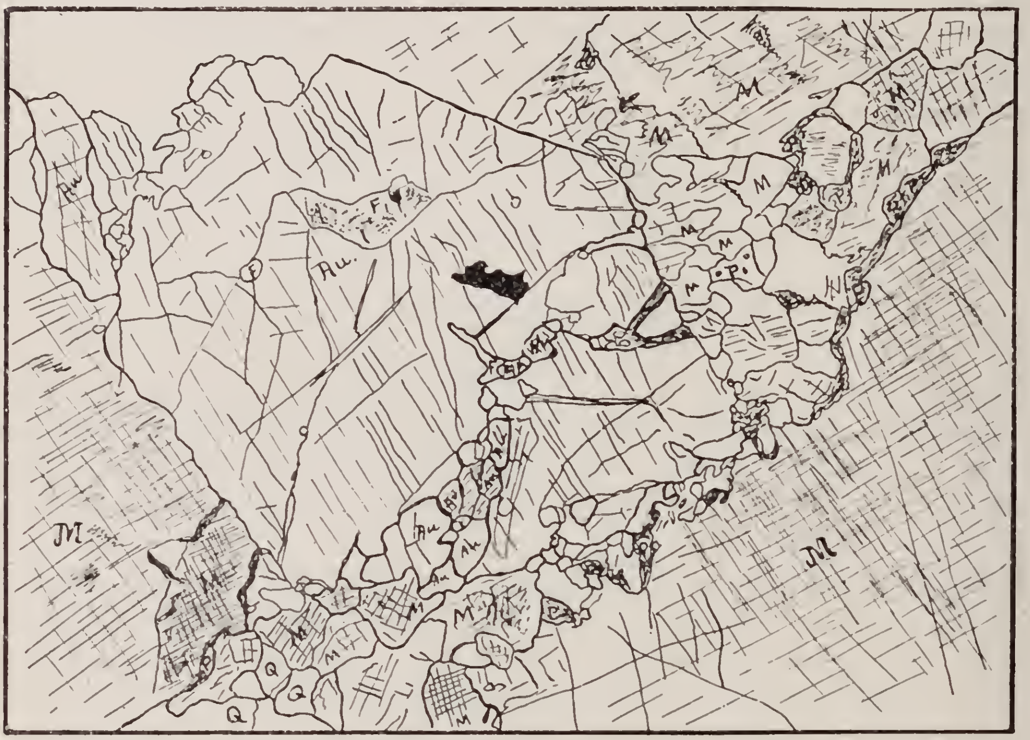

FIGURE 5.—*Section Transverse to granular Bands in the coarse Syenite-gneiss.*

Showing augite crystal broken in the portion projecting into the granular band. *Au* = augite ; *M* = microcline ; *P* = plagioclase ; *Q* = quartz ; *F* = feldspar.

The large microcline and augite grains, which constitute the larger part of the section, are traversed in places by a series of irregular cracks, which lie parallel with the lines of fluid inclusions in the quartz.

The augite sometimes shows the effects of mechanical movements in the fracturing and breaking of a grain lying in contact with the granular zone.

The grain shows fracturing throughout, but the breaking appears greatest along the side adjacent to the granular area. As shown in figure 5, one fragment has been separated slightly from the main portion and small grains of augite lie distributed along the crack. Some of the small grains of augite are very slightly pleochroic, though the main part of the crystal is not.

In specimen 125 (127) the chief constituents are also coarsely crystallized. The microcline has a purplish gray color, and incloses large prisms of augite similar to that previously described, except as to the size of the individuals. The pyroxene in the interstitial areas, however, is without idiomorphic outlines, and occurs mostly in large, irregular grains and aggregates. These are of a lighter green than the idiomorphic individuals in the microcline, and contain a larger number of inclusions of feldspar, titanite and pyrite. This becomes apparent in attempting to select the augite for chemical analysis. The anastomosing granular bands separate the rock into angular lumps of irregular sizes. These bands are not always plainly apparent in the hand specimen, but are revealed with distinctness by the microscope.

FIGURE 6.—*Section showing granular Band intersecting the Rock.*

Ap = apatite; Q = quartz; P = plagioclase; M = microcline.

In thin section (number 127) the coarsely crystallized feldspar shows a beautiful development of the crosshatching of microcline. The augite and large microcline grains meet each other with tolerably sharp boundaries, though a small amount of granular microcline and augite is sometimes observable along the line of contact. There are also narrow bands of granular microcline extending outward from the angle of the augite grain along the spaces between the large grains of microcline. In these zones of granular microcline there occur also small grains of plagioclase. Between the grains of microcline and plagioclase there appears in places, as a cement, a very small amount of feldspar in which fine striations may sometimes be detected.

The microcline is sometimes clouded and contains occasional small plates of biotite, rutile needles, and apatite.

The augite occurs in irregular grains, usually elongated parallel to the vertical axis. It is of a pale green color and nonpleochroic. The prismatic cleavage is well developed. Cleavage parallel to the orthopinacoid and clinopinacoid is common, though usually less distinct than the prismatic. Grains in which the cleavage parallel to $\infty P \overset{\prime}{\bar{\infty}}$ (100) is well developed, giving a diallage-like appearance, are frequent. This is often made more apparent by the presence of thin twinned lamellæ parallel to the same plane. Inclusions of feldspar, sometimes showing the cross-hatching of microcline, occur in the augite. Grains of pyrite occur along the cleavage, as also small, irregular flakes of hornblende. The hornblende is green and pleochroic in green and greenish yellow colors.

The alteration of the augite to compact hornblende was clearly demonstrated by the presence of the latter along the fracture cracks of the former. At one point in the crack there is a small grain of compact green hornblende partially inclosing a grain of iron ore. The hornblende shows well marked parallel cleavage and distinct pleochroism. In addition to this, the irregular fracture lines of the augite are bordered on either side by a thin greenish band, differing from the augite in its double refraction and showing distinct pleochroism. These bands are in direct continuity with hornblende in the larger space and must be regarded, therefore, as the same. The zone of hornblendic substance is often observed along the fracture lines in the augite and grading into the latter. They are so narrow, however, that, though showing a slight degree of pleochroism, their identity is clearly established only when found in direct connection with larger recognizable masses.

The apatite occurs both in the form of microscopic inclusions in the microline and as rather large rounded grains, both in the microline and in the interstitial areas. These often inclose small grains and prisms with pyramidal terminations, having a lower index of refraction, which are probably quartz. In one of these inclusions the extinction was found to be parallel to the longer axis.

In thin sections of specimen number 126 (128), which resembles the preceding, the granular zones are narrow and consist chiefly of microcline with a very small amount of plagioclase. The large grains of microcline show the characteristic microperthitic intergrowth with albite (?).

The microcline holds as inclusions numerous small biotite plates, apatite, rutile needles, and an abundance of fluid inclusions. The biotite plates are often distributed along the cleavage in parallel lines or bands. In other cases they appear in considerable numbers in prisms and hexagonal sections in intersecting parallel lines corresponding to the cleavage. Dust-like decomposition products appear quite abundant in some areas, and especially along fracture lines.

An aggregate of augite grains, with irregular, but rounded, outline, occupies the space between two large microcline individuals. The augite and the coarse feldspar meet each other for the most part in well defined boundaries. In some places, however, a small amount of finely granular microcline occupies the space between them. Rounded grains of calcite, pyrite and microcline are inclosed in the augite. The fracture lines affecting the microcline sometimes extend uninterruptedly through an adjoining augite grain.

Specimen 128 (130) has a more even and finer grained texture than the preceding, and likewise a more uniform distribution of the constituents.

In thin section the microcline shows a less clearly defined grating structure than in the foregoing, and occurs in irregularly angular and rounded grains from two to five millimeters in diameter, usually separated from each other by a network of finely granular microcline, inclosing here and there larger grains of augite and a small amount of quartz, titanite and calcite, but sometimes meeting each other along a common boundary. The proportion of augite is much less than in most of these rocks. The interstitial granular areas consist of very small grains of microcline and augite, with a small amount of clear, fresh-looking plagioclase feldspar between them in places. The augite does not appear to have suffered much disarrangement of parts, though coarse fractures are common. A small amount of pyroxene occurs in small grains distributed in the granular microcline bands. In one instance a grain lying at the intersection of three granular bands shows a line of fracturing extending diagonally across the parallel cleavage, while narrow zones of hornblende with faint pleochroism border a set of fractures developed transverse to the cleavage. There is a slight difference in extinction and discordance in the direction of the cleavage in the two parts into which the diagonal crack divides the grain. Along this crack there appear small grains of apparently fresh feldspar and one of titanite, together with several small augite grains. A diallage-like appearance due to polysynthetic twinning parallel to the orthopinacoid appears in some grains. No differences were noted between the large idiomorphic augite grains and those appearing in the granular areas. They show little evidence of alteration. More or less quartz is present in the granular areas usually carrying rutile and fluid inclusions and in some cases small rounded granules of augite. Calcite, apatite, titanite and iron pyrites appear in small amounts. The apatite carries small inclusions of quartz.

Specimen 129 (131) resembles the last, except that the microcline has a lighter color, giving the rock a fresher appearance. In general, the texture is medium to coarse, with much larger grains of microcline scattered through the mass. The augite and titanite appear quite uniformly distributed, but on close inspection the former may be observed slightly aggregated in anastomosing lines, giving an obscure net-like aspect. On one side the specimen shows a flat surface, along which shearing has taken place.

In thin section in some areas a small amount of granular microcline appears in the spaces between the larger grains. Plagioclase feldspar occurs as small, irregular, unstriped grains in the interspaces and in small amount as a cement. The microcline in general shows greater alteration than in the preceding specimen. Numerous particles of epidote and occasional scales of biotite are scattered through it. Epidote also occurs in connection with the augite.

The augite agrees with that of the preceding specimen. In one case a grain having a pronounced twin lamination parallel to the vertical axis has been much fractured and partially squeezed in two at the middle. The two parts on either side of the major fracture are slightly changed in orientation, while small grains of plagioclase, feldspar and green hornblende occupy the crack. A large grain of apatite inclosed in the augite adjoins the crack. The augite is cut nearly parallel to the clinopinacoid, $\infty P \grave{\infty}$ (010), and shows an extinction angle of 43° for the thicker lamellæ and 33° for the fine. It is evident, therefore, that the lamellar structure is not due to a fine interlamination of an orthorhombic pyroxene (hypersthene), as might be supposed, but represents a multiple twinning, probably representing gliding planes, due to pressure.

The part of the grain showing greatest fracturing also shows decomposition products in greater abundance. These consist of epidote, calcite, and hornblende; the latter in small pleochroic grains scattered along the fracture lines. In one case, showing only parallel cleavage, the extinction measured upon the cleavage lines was 13 degrees. In some cases an aggregate of small grains of augite have a considerable amount of hornblende in the form of small flakes and grains associated with the augite.

Brown biotite appears in small amount, apparently as a decomposition product.

A mass of rock four feet long, observed on the dump of opening number 11, showed the gradation from the first into the second or ellipsoidal variety.[*] Specimen 136 (139, 140) was taken about 15 inches from the ellipsoidal end of the block. It consists of coarsely crystallized areas of feldspar and augite, with intervening areas in which the constituents form a moderately fine grained mixture. The augite occurs in large and small grains, the latter in the granular areas. The feldspar (microcline) has a gray color and shows a sharp but variable reflection from the cleavage faces. Twinned individuals having the greatest extent parallel to the twinning plane are common. The augite and titanite both

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[*] This block is represented in the collection by numbers 134, 135, 136 and 137, taken in consecutive order, the last number being the leopard rock.

appear in larger grains in the more coarsely crystallized portions. In the finer grained areas the constituents are quite uniformly distributed. In thin section the microcline shows a pronounced development of microperthitic intergrowth with a more strongly doubly refracting, fresh-looking feldspar (albite ?). In some sections the albite bands show a very fine transverse striation, upon which the extinction is about five degrees. Sometimes small grains of quartz appear inclosed in the albite bands. The inclusions appearing in the microcline occur also in the albite bands and in the quartz and correspond to those already described. In some cases plates of biotite extend across the boundary between the microcline and albite and are partially inclosed in each.

The space between the microcline grains is occupied by finely granular microcline and a striated feldspar, with here and there larger grains of green augite. The striated feldspar is fresher in appearance than the microcline. The laminations are very fine, and according to a number of measurements extinguish at from 4° to 5° on either side of the twinning plane where this bisects the angle of extinction of the two lamellæ, thus corresponding to albite or oligoclase. In addition to biotite plates, these plagioclase feldspars often contain large numbers of rounded or nodular inclusions of quartz.*

Specimens 134 (137) and 135 (138), taken from the same block as the above, are much finer grained and contain a considerable amount of quartz, showing with the feldspar a somewhat obscurely banded arrangement. Augite is present in comparatively small amount. The feldspar is pinkish, except in the coarser patches, where it is the usual gray color. Grains of microcline up to the size of peas, sometimes inclosing augite, occur scattered through the finer grained areas. Under the microscope these specimens are seen to differ from the preceding in the greater extent of the interstitial granular areas, the lessened amount of augite, and greater abundance of quartz.

In addition to the microperthitic intergrowth with albite, the larger microcline grains show an abundance of the nodular quartz inclusions, with here and there similar forms made up of an aggregate of albite grains. These nodular quartz inclusions are of considerable size, varying from .035 of a millimeter to .425 of a millimeter in diameter, the larger ones sometimes reaching a length of .95 of a millimeter. The largest individuals are often separated into a number of parts, each with slightly different extinction. It is noticeable that in many of them the more prominent fractures extend nearly in the same direction. In the granular

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*These correspond to the "quartz de corrosion" of the French authors, a term quite inappropriate, as they in no sense represent corrosive action. In correspondence with their peculiarities of shape, the term "nodular quartz" is here adopted for them.

zones there is an abundance of fresh, finely and sharply striated feldspar usually carrying nodular quartz inclusions.

The quartz occurs distributed through the fine mosaic, often in lines and stringers of elongated grains, in which, in addition to fluid inclusions, the inclusions found in the microcline are abundant.

Epidote appears in particles distributed through the microcline, while the titanite often occurs in association with an opaque iron ore, probably ilmenite.

ELLIPSOIDAL SYENITE-GNEISS OR LEOPARD ROCK.

The collection embraces specimens showing a gradation from forms in which the constituents are rather coarsely crystallized and the feldspathic cores approximately ellipsoidal through others in which they become more and more elongated, flattened and distorted, accompanied by a decrease in the size of the grains, to those finally in which the constituents are fine grained and arranged in parallel bands. The specimens were taken from the dumps, which offered excellent opportunities for securing an abundance of fresh material.

Specimen 137 (141, 142, 143), which was taken from the block furnishing specimens 134, 135, 136, represents the ellipsoidal rock in contact with a mass of apatite, the ellipsoids sometimes thrusting themselves in between adjoining masses of apatite which may have belonged originally to the same deposit.

The interior of the feldspathic lumps is sometimes coarse grained and identical with portions of number 136. They also show a small amount of augite intergrown with the feldspar in these coarse grained parts, while the finer grained, outer peripheral portions show little, if any, augite.

Quartz is present in considerable amount in lines parallel with the longer axis of the lump. In thin section cut transverse to the pyroxene bands they are seen to consist of a fine grained mosaic of feldspar, quartz and augite, while the ellipsoids are composed chiefly of microcline in much larger grains. In some cases, however, the ellipsoid is more or less fine grained throughout and has lines of quartz extending through it parallel with the longer axis of the lump. The augitic bands correspond in structure with the granular belts observed in the coarse syenite. The constituents all show a pronounced tendency toward a laminated arrangement. They consist of microcline and plagioclase in about equal proportions, mostly in small equidimensional grains. Quartz is quite abundant, mostly in elongated grains and aggregates arranged in lines parallel with the lines of augite. They contain as inclusions small plates of biotite and occasionally small rounded grains of augite, unstriped feldspar, and small rhombic sections of titanite.

The plagioclase is generally fresh, with sharply defined striations, but in some cases is without stripes and more or less cloudy. It contains an abundance of nodular quartz inclusions. The constituents of the granular areas show a tendency toward the micropoikilitic structure.

The augite occurs in grains and aggregates distributed in a belt along the middle of the granular band. The grains are irregular in outline and often elongated parallel to the vertical axis. The grains usually lie with their long axis approximately parallel with the direction of the band, but in many cases they lie transverse to it. The augite grain is often pleochroic, but without distinct evidences of alteration. It does not differ essentially from that of the coarse grained rock. Pinacoidal and prismatic cleavages are usually well developed in the larger grains.

FIGURE 7.—*Section transverse to the Pyroxene Band in the ellipsoidal Syenite-gneiss.*

Showing prisms of augite lying in the granular bands and transverse to it.

Apatite occurs sometimes in large elongated grains lying parallel with the general lamination. They carry numerous quartz inclusions, sometimes in short prisms terminated at each end by the pyramid.

A small amount of calcite is present.

In specimen number 142 (147, 148, 149) the feldspathic lumps are mostly small, usually much elongated, and very irregular in shape. The pyroxene is abundant in the interstitial areas, but is not regularly distributed. In places it occurs in lumps of considerable size, in which there appear grains of quartz and feldspar and a considerable amount of titanite. The flattened feldspathic lumps arrange themselves somewhat concentrically about these aggregates. The flattened feldspathic masses are relatively small near the central augite aggregate, but increase rapidly in size outward. Often the augite lump represents simply a local thickening of the interstitial band. The augite is of a dark green color and occurs in comparatively large prisms, those of the segregated masses occasionally exhibiting crystallographic outlines. In the interstitial bands the prisms sometimes arrange themselves transversely and project more or less into the feldspathic masses on either side. The feldspathic lumps are made up of a groundmass of fine grained feldspar and quartz inclosing large, often twinned, tabular grains of microcline.

The size of the large microcline grains is, in general, proportional to that of the feldspathic lump. The titanite occurs chiefly in association with the augite. It appears also in the feldspathic areas, but less frequently.

In thin section the microcline grains of the feldspathic lumps are found to measure from 1½ millimeters to 2 millimeters in diameter, while the granular matrix in which they lie is composed of grains of microcline and plagioclase varying in size from .3 of a millimeter to .6 of a millimeter.

The small grains of microcline in the granular areas often appear cloudy at the center, while the outer portion is clear and fresh. The same appearance is also observable in some of the plagioclase grains. In these and in many other sections the granular feldspars are often seen to meet each other in straight, sharply defined boundaries, suggesting an approach to crystallographic outlines. This tendency is especially pronounced in grains in which the outer zone is fresher than the interior. The larger microcline grains are filled with particles of epidote, plates of biotite, fluid inclusions, and occasionally microscopic grains of tourmaline. They are generally much fractured and in some cases show cracks filled with calcite. Quartz, calcite and plagioclase feldspar occur in the augite, often, but not always, in connection with fractures. Small aggregates of hornblende needles, accompanied by an opaque iron ore, appear occasionally as alteration products of the augite. The latter often shows distinct pleochroism:

$\mathfrak{a}$=greenish yellow.
$\mathfrak{b}$=green.
$\mathfrak{c}$=green or slightly yellowish green.

Quartz is not plentiful.

In number 143 (150, 151, 152, 153) the ellipsoidal masses are larger, but are more or less flattened and contain a considerable amount of quartz.

Under the microscope the interstitial areas show a pronounced development of the granular or "mörtel structure," in which in some places there appears a preponderance of plagioclase beset with an abundance of nodular quartz, while in others granular microcline predominates.

The constituents have the relations characteristic of the micropoikilitic structure. The larger grains of microcline sometimes show the effects of dynamic agencies in the bending of the lamellæ and undulatory extinction. The augite occurs in irregular grains and aggregates distributed along the middle of the granular band, as usual.

Quartz is quite abundant in angular, often elongated grains. They sometimes inclose small, rounded grains of pyroxene, which in one case appeared to stream out from a large augite grain adjoining.

The apatite occurs, as usual, in rounded and elongated grains, sometimes inclosing rounded grains of augite.

In specimen 149 (161, 162) the feldspathic ellipsoids are drawn out into irregular, flattened, disk-like forms. The rock shows a tendency to cleave along the face of the augite bands when the breakage is parallel to the longer axes of the disks.

Under the microscope both feldspar and augite are much finer grained than in the preceding. The latter especially appears in smaller and more rounded grains, which lie distributed in a linear direction in the granular feldspathic matrix. The diallage-like structure, due to the presence of twinned lamellæ parallel to the orthopinacoid, appears sometimes in sections cut transverse to the vertical axis. Indications of orographic pressure appear in one instance in the breaking of an augite grain, calcite being deposited in the crack, and, further, in the appearance of fractures extending across adjoining grains of pyroxene. The granular feldspar grains often meet each other in sharp, straight lines. In one case two grains of microcline, one of which is bordered by a small amount of fresh plagioclase feldspar, are separated by a narrow band of the latter, which in polarized light is seen to be twinned, the part on either side of the twinning plane being very nearly, but not quite, in optical orientation with its adjacent microcline grain.

In specimen 138 (144), taken from the dike intersecting the pyroxenite and quartzite, shown on page 101, the feldspathic lumps and interstitial bands are both of a uniformly fine grained granular texture.

In thin section the feldspathic lens-shaped masses are shown to consist of rather fine but relatively uniform grains of microcline, with a moderate amount of quartz and the usual portion of titanite. Occasionally the microcline carries nodular quartz inclusions, but they are few.

In the interstitial zones the constituents are somewhat finer, and the grain lie with their longer axes extended in the same direction. The granular feldspar has the characteristic structure of microcline, while plagioclase is almost altogether wanting. However, these granules carry a considerable amount of nodular quartz.

The augite appears in small grains disseminated in the granular feldspar matrix. This specimen differs from the preceding in the presence of a considerable amount of hornblende associated with the augite; sometimes connected with it zonally. Some of the hornblende presents idiomorphic outlines with well developed prism faces meeting at angles of 56° or 124.°

STREAKED SYENITE-GNEISS.

Specimen 140, associated with the last in the exposure described on page 101, shows a nearly complete flattening of the ellipsoids, giving a well developed gneissoid banding. Its identity with the leopard rock, however, is plainly evident from the anastomosing of the augite streaks visible on a transverse fracture face. Specimen 156 (186), taken from the dump, represents the same structure in a fresher rock. The constituents appear in a remarkably fresh condition. The feldspathic areas have been completely flattened, so that on a fracture face parallel with the plane of the greatest and least axes of the flattened ellipsoids the constituents are seen in parallel bands. When the rock breaks transverse to this and the augite bands, the latter are seen to coalesce. The mass of the rock is fine grained, with large crystals of microcline scattered here and there along the feldspathic bands.

Under the microscope the rock is seen to consist chiefly of finely granular feldspar, with larger grains of feldspar and augite scattered through the groundmass. The granular groundmass consists of microcline and unstriped feldspar, the latter occurring both as a cement and in small grains carrying numerous nodular quartz inclusions. A small amount of striped feldspar is also present.

FIGURE 8.—*Idiomorphic Hornblende Crystal in the streaked Syenite-gneiss.*

Ap = apatite; *Au* = augite; *H* = hornblende; *T* = titanite; *M* = microcline.

The granular microcline generally appears fresher than that in large grains, and in some cases appears more cloudy at the center than in the peripheral portions.

The augite grains vary greatly in size, but in general are intermediate in size between the microcline of the groundmass and the large porphyritic grains. They lie scattered along planes in alternation with the bands of feldspar. Hornblende is present in considerable amount, associated with the augite. It does not occur outside of the augite bands. Its relations to the augite, however, are not such as to clearly prove its derivation from that mineral. It sometimes appears in small flakes along the cleavage lines of the augite and is frequently in zonal relation with the latter. It shows the relations with the other constituents characteristic of the micropoikilitic structure, and frequently appears in crystals with characteristic crystallographic outlines.

In figure 8 it is evident that the hornblende is the result of a separate crystallization, as shown by its idiomorphic form and relation to the adjacent minerals. The manner in which it incloses the apatite shows that it has crystallized subsequently to the apatite. Moreover, its perfection of outline indicates that it has not passed through the varied experiences to which the original constituents of the rock may have been subjected. It does not have the crystallographic relations with the augite characteristic of paramorphic development. Titanite also appears here, often in small rhombic crystals.

Specimen 155 (166) shows a pronounced plication of the bands. Along with this the rock shows more or less schistosity in certain directions. The direction of this cleavage, however, has no apparent relation to the direction of the gneissoid banding. The augite streaks are less sharply defined than in the specimen last described (156).

Under the microscope there appears a uniformly very thin, fine grained groundmass of feldspar and quartz, in which large grains of microcline and numerous small grains of augite and hornblende arranged in bands occasionally occur. It is somewhat more granular than the preceding, but in other respects does not show any marked differences.

Character and Relations of the Rocks.

The relations of these rocks as observed in the field are thus seen to be borne out by their petrographical character. Beginning with the coarsely crystallized rock, in which the gneissic structure is but imperfectly developed, there is a gradation into finer grained and more gneissoid forms, until we have in the last stage a well developed gneiss. In its typical form it consists of a mixture of microcline and augite as essential constituents, while quartz, titanite and pyrite play an accessory role. A peculiar feature of this rock is the large size of the microcline and augite grains and the segregation of both in lumps and patches. The plagioclase feldspar appears in proportion to the extent of the granular areas and constitutes an essential feature of these areas, though usually playing a less important part than the microcline grains. It is usually much fresher than the microcline, but in some cases the opposite is true.

The augite, which occurs in large crystals and grains or segregated masses in the coarse grained rock, also appears in smaller grains as the rock becomes more granular and gneissoid, distributed along the middle of the gneissoid bands.

The constituents of these bands are strictly allotriomorphic in their relations and often show a distinct micropoikilitic structure. These indications of recrystallization become more pronounced in the more gneissic forms. The indications of secondary enlargement of the microcline, and sometimes of plagioclase grains, are also more apparent in these latter specimens. In the coarse grained rock plagioclase feldspar is generally present in small amount as a cement between the grains of microcline. This cement-like arrangement is also apparent to a small extent in the more gneissoid variety, but is overshadowed by the general appearance of recrystallization. The idiomorphic character of the augite inclosed in the microcline is wholly absent in all the pyroxene grains appearing in the granular groundmass. These grains often appear prismatic, but never have regular outlines. They frequently lie transverse to the augite band, giving the radiate arrangement already noted.

The evidences of dynamic movements appear in the coarse rock in the fracturing and breaking of the constituents and the presence of cracks extending uninterruptedly across adjoining grains. The last feature was less apparent in the more gneissic rock. The grains of augite usually show an abundance of coarse fractures and occasionally a broken grain with parts slightly disarranged. The appearance of breaking occurs in the augite in the granular bands only, and if these bands represent lines of breakage, as is believed, the fracturing of the pyroxene may be correlated with the agencies which initiated the development of the gneissic structure. No distinct evidence of the derivation of the granular pyroxene from the coarse grains and crystals could be made out.

Hornblende does not appear to have been present in the original intrusion. It sometimes appears in a very small amount in connection with the augite, sometimes as an alteration of the latter. In these cases it is destitute of crystallographic form. In the gneissic rock, however, the hornblende becomes quite abundant and often presents well marked idiomorphic outlines.

The quartz in the coarse granular rock, as in the case of the feldspar and augite, appears to be distributed in patches. It is apparently more abundant in the more gneissic rock, where the grains assume elongated forms and are arranged more and more in lines.

The laminated gneissic arrangement of the constituents is a marked characteristic of the granular bands. In those of the coarse grained rock it is not marked. It is indicated, however, by the tendency of the quartz grains to become elongated parallel with the band. In the leopard rock there is a distinct lamination of the constituents in the interstitial zone. In cases where the feldspathic lumps are more or less granular throughout, the constituents tend to assume a laminated arrangement, but this is not common.

NOMENCLATURE.

The characteristics of the streaked gneiss here described correspond to what, according to Zirkel,* may be regarded as a pyroxene-gneiss (augite-gneiss). A somewhat similar rock, but apparently containing less augite, has been described by Lacroix as granulitic microcline-gneiss.†

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* Lehrbuch der Petrographie, band iii, p. 219.

† Bulletin de la Société Française de Mineralogie, April, 1889.

The term pyroxene-gneiss has been applied by the last named author to rocks, of much more basic composition than those under consideration, corresponding to the pyroxenites of the apatite region.

It requires but a brief survey of petrological literature to become aware of a great difference in usage as to the term gneiss. By some authors the mineralogic composition of these rocks is made the basis of definition, and, being regarded as having the greatest analogy with the granites, they are defined as characterized by the presence of feldspar and quartz as essential constituents.[*]

By many, however, the term is employed in a structural sense to denote the coarser schists, which so often present granitoid characters—a more comprehensive and preferable usage, since the gneissoid or foliated structure may characterize rocks of very diverse composition. The difficulty attending the application of a mineralogical definition is acknowledged by Zirkel when he attempts to draw the line between certain hornblende-gneisses and amphibolite.[†]

The mineralogical definition precludes the use of the term syenite-gneiss. This name, however, has been used for a quartz-bearing hornblende-gneiss and is given as a synonym for this rock by Geikie.[‡] Naturally enough Zirkel does not recognize such a division and sets the term aside as misleading.[§] On the whole, it seems to the writer that the broader use of the term gneiss in the structural sense is to be preferred. This usage prevails quite generally among the English and French petrographers.

The principles applicable to the classification of the gneisses may be summarized as follows:

1. Their mineralogic composition.
2. Identity in composition and texture with the igneous or sedimentary rocks. Origin unknown.
3. Identity in origin, composition and texture with igneous or sedimentary rocks. Under this we have to consider (*a*) those rocks in which the gneissoid structure is due to dynamic agencies, and (*b*) those in which it is the result of conditions attending their original solidification.

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[*] Zirkel: "Zum Wesen des eigentlichen Gneisses gehört das jedesmalige Dasein von Kalifeldspath, Quarz und von einem triklinen Kalknatronfeldspath oder Natron-feldspath. . . . Wesentlichen Bestandtheile der Gneisses im Allgemeinen bilden aber noch ausserdem Magnesiaglimmer, Kaliglimmer und Hornblende, welche indessen nicht in sammtlichen Gneissen vorkommen, sondern einzeln oder zu zweien auf gewisse Abtheilungen derseben beschränkf sind." (Lehrbuch der Petrographie, band iii, p. 185, 1894.)

[†] Es ist schwer die Grenze gegen die letzeren (feldspath-quarz haltigen Amphiboliten) zu ziehen, aber nicht wohlgethan, Gestein mit sehr vorwaltender Hornblende zu den Gneissen zu rechnen. Namentlich ist es auch nicht zu billigen gar quarzfreie feldspathaltige Amphibolite diesen Gneissen zuzuzählen. Ferner bedingt der Name Gneiss immerhin ein gewisses planes Parallelgefüge. (Lehrbuch der Petrographie, band iii, p. 215, 1894.)

[‡] Text-book of Geology, 3d edition, p, 186.

[§] Lehrbuch der Petrographie, band iii, p. 215, 1894.

All of these principles are recognized by petrographers, though usage varies greatly as to their application in the naming of the rocks. Thus, according to some, the specific designation is based upon the prevailing mineral characteristics, while others prefix the names of other rocks with which the gneiss agrees in its textural or mineralogical characters. The latter is the prevailing usage among the Canadian geologists, who apply the term quartzite-gneiss, diorite-gneiss, etcetera, as specific designations to granitoid rocks possessing a parallel structure. Some geologists[*] restrict the terms syenite-gneiss, diorite-gneiss, gabbro-gneiss, etcetera, to rocks in which there appears a gneissoid structure due to differential movements acting upon the igneous mass in the later stages of its original consolidation.

The desirability of greater uniformity in the method of naming the gneisses is apparent. The following slight modification of methods in quite general use is suggested as a step in this direction:

1. That the term gneiss be used in its broader structural sense for all rocks showing a laminated or banded structure and in which the gneissoid structure is *not known* to be due to differential movements of the igneous mass before its final consolidation. For the latter a structural qualifying term may be used, as has already been done by Geikie and others, as gneissoid or banded gabbros, etcetera.
2. That where the origin of the rock (whether igneous or sedimentary) is known, the class designations be made to correspond with the character of the original rock. Thus a gneiss known to have consolidated originally as a diorite may be termed diorite-gneiss.
3. In those cases where the character of the original rock is unknown, comprising probably the larger part of the group, the extent of knowledge with reference to this point may be indicated by the ending "ic." Thus a rock with gneissic structure and corresponding in its mineralogic composition with the diorites, but whose geological relations are unknown, may be called a dioritic-gneiss.

The following table illustrates these principles as applied to a few of the more important types of rocks:[†]

Gneiss.

Analogous massive type.	Of igneous origin.	Origin unknown.
Granite:[‡]	Granite-gneiss:	Granitic-gneiss:
Biotite-granite.	Biotite-granite-gneiss.	Biotite-granitic-gneiss.
Hornblende-granite.	Hornblende-granite-gneiss.	Hornblende-granitic-gneiss.
Syenite:	Syenite-gneiss:	Syenitic-gneiss:
Hornblende-syenite.	Hornblende-syenite-gneiss.	Hornblende-syenitic-gneiss.
Mica-syenite.	Mica-syenite-gneiss.	Mica-syenitic-gneiss.
Pyroxene-syenite.	Pyroxene-syenite-gneiss.	Augite-syenitic-gneiss.
Diorite:	Diorite-gneiss:	Dioritic-gneiss:
Mica-diorite.	Mica-diorite-gneiss.	Mica-dioritic-gneiss.
Gabbro.	Gabbro-gneiss.	Gabbroic-gneiss, or gabbric-gneiss.
Pyroxenite.	Pyroxenite-gneiss.	Pyroxenitic-gneiss.

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[*] J. G. Goodchild: The Geol. Mag., new ser , Dec. IV, vol. I, number 1, p. 27 (Jan , 1894).

[†] As types of the sedimentary formations, there may be quartzite-gneisses and quartzitic-gneisses.

[‡] In the absence of a better name, the term "granite" is here used in its restricted petrographic sense.

In accordance with this view, the classification of the rock under consideration is obvious. It is a gneissoid pyroxene microcline rock, which in some places is almost or wholly free from quartz and corresponds to a pyroxene-syenite, while in others not far distant the increase in the amount of quartz would ally it to the pyroxene-granites. In view of the generally sparing amount of quartz present in the coarse grained forms, they are here referred to generally as pyroxene-syenite-gneiss or simply syenite-gneiss, though it is not to be overlooked that these grade into more quartzose forms, which may be more fittingly regarded as pyroxene-granite-gneisses.

W. G. Ferrier* describes a gneiss from the Château Richer district apparently identical with the "streaked gneisses" described above, to which he applies the name "pyroxene-granite-gneiss."

Lawson † describes a rock from the Rainy Lake region, which he terms hornblende-syenite-gneiss and which he states is not separable geologically from others of the same region which he calls hornblende-granite-gneiss. From his description of these rocks it is evident that, except in the ellipsoidal structure and the character of the prevailing ferromagnesian constituent, these rocks show many points of resemblance to the syenite-gneisses of the Du Lievre region. If the view held by Lawson as to the origin of the Rainy Lake rocks is sustained, however, they should be called gneissoid syenites.

ORIGIN OF THE ELLIPSOIDAL STRUCTURE.

GENERAL HYPOTHESES.

Recognizing the intrusive character of the rock, in seeking an explanation of the peculiar ellipsoidal structure two hypotheses suggest themselves:

A. That it is primary and represents differentiation of the magma; or,

B. That it is secondary and due to dynamic movements subsequent to solidification.

In applying any theory to the phenomena in question we have to consider its competency to explain—

1. The interstitial arrangement of the augite about the ellipsoidal masses;
2. The gradation between this and the segregated lumps and crystals in the coarsely crystallized rock on the one hand, and the parallel arrangement of the streaked gneiss on the other;
3. The presence of the gneissic microstructure and the progressively greater granulation of the constituents as we proceed from the least to the most distinctly gneissoid forms;

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* Notes on the microscopical character of some rocks from the counties of Quebec and Montmorency, Canada. Number 14*a*, p. 9.

† A. C. Lawson: Annual Rept. Geol. Survey of Canada, 1887–'88, vol. iii, part 1, p. 120 F.

4. The transverse arrangement of the augite and manner of crystallization of all the constituents of the interstitial granular bands;

5. The concentric arrangement of the lumps and bands about inclosed masses of apatite or pyroxenite;

6. The occurrence of the apatite usually in a more or less crushed condition, but exceptionally in large crystals imbedded in the leopard rock; and

7. The abrupt transition between the different phases in their field relations.

PRIMARY ORIGIN.

Differentiation af the coarse syenite.—If, as seems probable, the coarse feldspathic rock represents very nearly the character of the rock at the time of consolidation from the original magma, it is evident that in places differentiation had proceeded to a considerable extent at the time of crystallization. The crystallization of the pyroxene appears to have been often well advanced before that of the feldspar began. A considerable proportion of the pyroxene, however, occurs in large grains and aggregates in allotriomorphic development with the feldspar. In seeking an explanation of this tendency of the pyroxene to become segregated, two views suggest themselves:

a. That it represents a primary differentiation of the molten magma; or,

b. That it is due to the fusion and recrystallization of included fragments of the pyroxenite.

In regard to the first view (*a*), if this tendency on the part of the constituents toward segregration represents a primary differentiation of the magma, it would seem to accord better with the more generally accepted theory that differentiation has taken place when the magma was quite fluid than with that which supposes it to take place by crystallization, mechanical accumulation and reliquefication. According to Professor Iddings,* a study of the chemical character of rocks shows that the differentiation of molten magmas is not according to stoichrometric proportions, and is therefore not a mineralogic differentiation. As to the method by which concentration has taken place, two views have been expressed: (1) that it is due to molecular diffusion, according to Soret's principle, advocated by Vogt,† Brögger ‡ and others; and (2) that it is the result of liquation as advocated by Durocher § and Bäckstrom. ||

If, according to Soret's principle, the differentiation of the magma be regarded as due to differences of temperature, then, in order to explain the lumpy segregation of the coarse grained rock, it may be necessary

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* J. P. Iddings: The Origin of Igneous Rocks. Bull. Phil. Soc. Wash., vol. xii, p. 152.

† J. H. L. Vogt: Geol. Fören, i, Stockholm Förhand., vol. 14, May, 1891, p. 476. Reviewed by J. J. H. Teall in the Geol. Mag., Feb., 1892. Zeitschr. f. prakt. Geol., 1893, p. 272.

‡ W. C. Brögger: Zeitschr f. Kryst. n. Min., Leipzig, vol. 16, 1890.

§ J. Durocher: Ann. des Mines, Paris, vol. 11, 1857, pp. 217-259.

|| H. Bäckstrom: Jour. Geol., vol. 1, 1893, p. 773.

to adopt Brögger's suggestion that a partial crystallization of the feldspar set in at the same time that the segregation of the basic ingredients was taking place. Bäckstrom considers* that the formation of basic inclusions by diffusion is improbable, since there can be no difference in temperature between these and the surrounding magma.

The second view (*b*), that the basic segregations may be due to the recrystallization of fused portions of the pyroxenite, is not improbable, though evidence of this is not at hand. The occurrence of inclosures of the pyroxenite in the syenite-gneiss is frequently observed. These, however, usually retain more or less angular contours and do not appear to have suffered very much from fusion. Professor Lawson has described † inclosures of hornblende schist in the Laurentian gneiss from the Rainy Lake region, which occur in sharply angular, subangular or somewhat rounded blocks, or as more or less attenuated bands drawn out parallel to the foliation of the gneiss and confused with it. He finds evidence of total or partial fusion and recrystallization to such an extent often as to admit of the deformation of the fragments and their being drawn out into lenses. He thinks that where the magma had higher temperatures the inclosures were entirely absorbed, leaving no trace of their existence except a more basic local facies of the gneiss.

Differentiation of the ellipsoidal rock.—On the assumption of a primary origin it may be held that the distribution of the pyroxene in the ellipsoidal rock represents—

a. A molecular differentiation of the original magma, or

b. That it is due to the movement of a partially differentiated magma.

In considering the first view (*a*) two hypotheses present themselves:

In the first hypothesis (I), which attempts to explain by Soret's principle the peculiar distribution of the basic minerals in the ellipsoidal rock, there arises at the outset great difficulty in conceiving conditions that would give a difference of temperature between the feldspathic lumps and the interstitial pyroxene bands. Moreover, the presence of the gneissic structure would seem to render this view improbable.

In the second hypothesis (II), based on the liquation theory, it may be assumed that there has been a separation of the magma into layers of different composition, and that owing to some disturbance they were broken up and subsequently crystallized in the forms observed. This, however, is considered improbable from the relations of the coarse grained and ellipsoidal varieties and the absence in the former of any indications of differentiation in layers such as the theory might lead one to expect. Moreover, the presence of the gneissic structure seems to preclude any

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* Jour. Geol., vol. 1, p. 777.

† A. C. Lawson: Annual Report Geol. Survey of Canada, 1887–'88, new series, vol. iii, part 1, p. 130 F.

view which does not take into consideration the movement of the magma during or following its differentiation.

According to the second view (*b*), the gneissic structure is regarded as the result of the conditions attending the intrusion and consolidation of the igneous magma. Professor Lawson considers* that he has abundant evidence to show that the granite and syenite-gneisses of the Laurentian were plutonic rocks which crystallized slowly from a thickly viscid, tough, hydrothermal magma. Up to the time of its final solidification this magma is supposed to have been subjected to differential pressures, which produced a flow in the mass to which the foliation of the gneiss is ascribed. Geikie and Teall have described† a gabbro in which there appears a banded structure almost identical with that of the Lewisian gneiss. This is regarded as inexplicable, either on the hypothesis of differentiation in situ or on that of successive intrusions, but is thought to have been produced by the deformation of a heterogeneous magma during intrusion.

In applying this view of the development of the gneissic structure to the ellipsoidal rock, two hypotheses are suggested based on the assumptions that may be made as to the character of the differentiation.

If in the first of these, which should be designated hypothesis III, we assume, as in the second hypothesis, a differentiation of the magma by liquation into lumps of feldspathic material separated by thin layers of basic material, then with a gradual movement of the magma it is evident that the forms would be drawn out more and more until the constituents became arranged in parallel bands. It is obvious that on the final solidification of the rock, a structure would result comparable in many respects with that of the leopard rock. As against this explanation, however, we have the following considerations:

1. The apparently cataclastic character of the gneissic structure and crystallization appearing in places. In the coarse grained rock granular bands occur as thin seams, like recemented cracks, separating the rock into coarse grained patches. These seams are sometimes too thin to be readily detected on the surface of the rock, but under the microscope show as narrow, sharply defined bands of granular microcline, fresh plagioclase feldspar and pyroxene inclosing the coarsely crystallized areas of microcline. These granular bands become more pronounced and regular in the ellipsoidal gneiss, where they constitute a well marked band between the feldspathic lumps, with larger grains of pyroxene distributed in a line along the middle of the granular groundmass. In the streaked gneiss the rock becomes granular throughout, though even here quite large grains of microcline often appear in the feldspathic bands.

2. The character of the coarse grained rock and the absence of any indication in it of the kind of differentiation assumed. If a regular lumpy aggregation may

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* A. C. Lawson: Ann. Rep't Geol. Survey of Canada, 1887-'88, new series, vol. iii, part 1, p. 139 F.

† Sir A. Geikie and J. J. H. Teall: Banded Structure of some Tertiary Gabbros in the Isle of Skye. Quart. Jour. Geol. Soc., Nov., 1894, p. 645.

occur as a result of primary differentiation, then it would frequently characterize intrusive masses, either with or without the presence of a gneissic structure. The absence of observations in support of this is proof presumptive that it does not exist.

3. The relation of the ellipsoids and pyroxene bands to the inclosed apatite crystals and masses. Their concentric arrangement about the apatite indicates that the formation of the apatite antedated the development of the gneissic structure. The difficulties in the way of considering that the formation of the apatite deposits took place in the original magma are:

a. Their large size. The deposits vary from a few inches in cross-section to several feet, and often extend many feet in horizontal and vertical directions. The crystals are frequently several inches in diameter. The larger crystals usually occur in pockets in the pyroxenite, associated with pink calcite, mica, etcetera. A crystal obtained at the Emerald mine, on the Du Lievre, and exhibited at the London Exposition in 1886, measured 62½ inches in circumference and weighed 550 pounds.* Crystals one to two inches in diameter frequently occur in the granular deposits. In pit number 11 at High Rock, a crystal five or six inches in diameter was observed in an inaccessible part of the wall imbedded in the ellipsoidal rock.

b. Their inclusions. Doctor Hunt noted rounded crystals of quartz and carbonate of lime as inclusions in the apatite.† Similar observations were made by Emmons,‡ while Harrington states § that the apatite crystals frequently inclose calcite, pyroxene, phlogopite, zircon, sphene, fluorspar and pyrite. While it cannot be positively asserted that these inclusions characterize the crystals imbedded in the ellipsoidal rock, the correspondence between these crystals and the other deposits as to their occurrence favors the supposition that they had a similar origin.

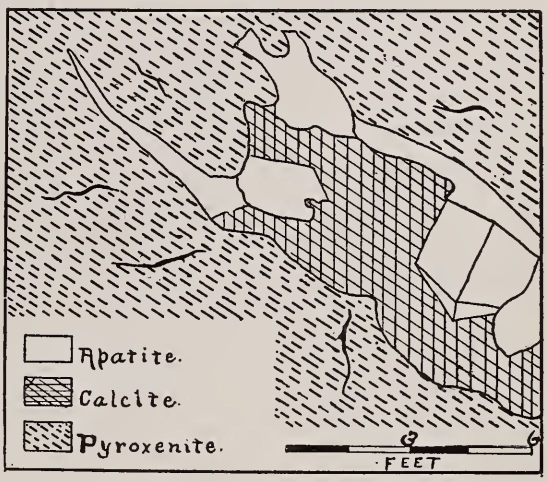

FIGURE 9.—*Pocket in the Pyroxenite filled with Apatite and Calcite.* (After Harrington.)

A large crystal of apatite projects from the side of the cavity.

c. The rounded outlines of the apatite crystals. This feature of the apatite crystals of the Laurentian veinstones was regarded by Emmons ‖ as due to partial fusion, while Hunt ¶ considered them to be the result of the solvent action of the heated watery solutions from which they were supposed to have been deposited. The appearance of rounded angles on crystals found in cavities in the pyroxenite seems to favor the latter view.

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* Descriptive Catalogue of the Economic Minerals of Canada, London, 1886.
† T. J. Hunt: Geology of Canada, 1866, p. 203.
‡ E. Emmons: Geology of the First District of New York, p. 57.
§ B. J. Harrington: Geol. Survey of Canada, 1877-'78, report G, p. 15.
‖ E. Emmons: Geology of the First District of New York, pp. 57, 58.
¶ T. J. Hunt: Chemical and Geological Essays (1891), p. 213.

d. The crushed condition of the apatite. The smaller deposits are generally more or less reduced to a granular condition. Often the peripheral portion is granular, while the interior consists of coarse grains and fragments of crystals, with fine granular apatite filling the interstices.

Hypothesis IV assumes that the heterogeneous character of the magma was due to the fusion of inclosed fragments of the pyroxenite and, owing to the differential movement of the mass, the absorbed material became distributed in the magma and crystallized in the form observed.

The presence of inclosures of pyroxenite in the syenite-gneiss has been referred to. In specimen 140 a somewhat rounded, subangular mass of pyroxenite appears in contact with the ellipsoidal gneiss. In some places the line of contact is well defined, but in others it is not. Under the microscope, however, the boundary is quite sharp and marked on the pyroxenite side by an abundance of scapolite (wernerite), while no trace of this mineral appears in the ellipsoidal areas. However, the pyroxene bands of the latter, which are cut off by the line of contact, are much more prominent adjoining the pyroxenite, gradually diminishing in thickness away from the boundary. Another instance is seen in specimen 153, not elsewhere described. In this there appears an irregular fragment of pyroxenite inclosed in the ellipsoidal rock. The structure of the latter is somewhat obscure. The pyroxene appears more abundant in the vicinity of the inclosure. Indications of orographic agencies subsequent to the development of the ellipsoidal structure appear in the schistosity of the rock and the presence of narrow bands of feldspathic material and rather large plates of biotite, which extend continuously across both the ellipsoidal rock and the pyroxenite. According to this hypothesis the apatite may be considered to have been derived from the pyroxenite and become more or less crushed and drawn out before the rock became wholly solidified. This hypothesis appears to be sustained by a number of considerations. The greater abundance of pyroxene in the vicinity of the inclosed masses of pyroxenite seems to indicate a partial absorption of the latter. The occurrence of interstitial pyroxene in greater abundance in certain areas in the ellipsoidal gneiss may indicate the position of smaller inclosures which have been entirely absorbed. Moreover, the character and condition of the apatite inclosures seem to favor this view. On the other hand, however, difficulties are encountered when we attempt to explain by this process—

The shell-like distribution of the absorbed pyroxenic material prior to solidification, and

The apparent cataclastic character of the gneissic structure.

That a more or less completely banded structure may be produced in this way, as claimed by Lawson,* is probably true, but whether the basic material may be so distributed as to crystallize out in the form shown in the ellipsoidal gneiss is doubtful.

While the argument drawn from the character of the gneissic structure is not beyond question, it is strongly presumptive against the primary origin of the ellipsoidal structure.

SECONDARY ORIGIN.

In attempting to explain the ellipsoidal structure by appealing to dynamic processes (hypothesis V), it is necessary to consider (1) the character of the original rock and (2) the agencies and their mode of operation.

The character of the original rock, as inferred from the coarse grained variety, was evidently peculiar. Its heterogeneous character is indicated by the tendency of the feldspar, pyroxene and quartz to appear in large grains, lumps and segregations. In some cases, however, the rock has an even, granular structure and consists of feldspar and pyroxene quite uniformly distributed. In places the rock is mostly coarse feldspar, with scattering grains and small aggregates of pyroxene. In other places the pyroxene occurs in much greater amount, both as crystals of various sizes and aggregates of grains, apparently constituting from 15 to 20 per cent of the rock. In general the irregular pyroxene aggregates vary from the size of millet seeds up to marbles, rarely larger. They usually inclose more or less feldspar in small grains; also pyrite and titanite. In areas showing a large amount of pyroxene the latter sometimes appears in idiomorphic grains, of large size, inclosed in the microcline. They also appear at times in the quartz areas. In the specimens showing a uniform distribution of feldspar and pyroxene, idiomorphic forms of the latter were not seen.

While the arrangement and mode of crystallization of the constituents seem to indicate partial differentiation of the original magma, it is not improbable that some of the pyroxene was derived from the inclosures of the pyroxenites, as already suggested.

The agencies which may be appealed to as effecting the changes observed are those usually classed under the head of dynamic metamorphism. These may be conceived to have effected the crushing of the coarse grained syenite, accompanied by solution, recrystallization and rearrangement of the constituents under the influence of water, and probably also of heat. The variation in the extent of the structural alteration may be due to the different attitudes of the inclosing rocks. It will scarcely be denied that certain portions of the intrusive mass

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* A. C. Lawson: Ann. Rep't Geol. Survey of Canada, 1887–'88, new series, vol. iii, part 1, p. 134 F.

would be called upon to sustain a much greater pressure than others, while some parts might escape almost wholly. With the breaking of the rock under the influence of strain there would be more or less pulverization of the minerals along the sides of the crack. This would favor the chemical action of percolating waters. With the recrystallization of the constituents taken into solution the crack would become healed. This may be conceived as taking place (1) by partial solution of the powder, with a secondary enlargement of the remaining portions; or (2) by complete solution and recrystallization of the pulverized material. In either case the filling would be fine grained, since even if wholly recrystallized the process would probably go on synchronously with the movement of the rock. Evidence that this process has taken place at a later date is sometimes seen in the presence of healed cracks cutting across the banding.

With increasing pressure the rock may be reduced to a coarsely fragmental condition, and if the process were stopped at this stage the result would probably be a mass of irregular fragments, cemented together by fine grained interstitial material. The pyroxene within reach of the percolating waters would be dissolved to a greater or less extent, and on subsequent recrystallization would appear in grains marking the spaces occupied by the solutions. The relative solubility of pyroxene and feldspar under the conditions here postulated is unknown. The relative effects of weathering, however, are well shown by the manner in which the pyroxene decays on exposed surfaces of the ellipsoidal rock, leaving sharp trenches surrounding the feldspathic portions. Since basic minerals melt at somewhat lower temperature than the acidic, it may be supposed that the temperature of the rock became sufficiently great to melt the pyroxene, but not the feldspar.* While the convoluted forms assumed by the ellipsoids are suggestive of plasticity, it is scarcely probable that the heat has ever reached the point indicated. This is inferred (1) from the occurrence occasionally of crystals of augite, which are apparently original, inclosed in grains of microcline in the ellipsoidal areas; and (2) from the consideration that if the heat is due to the shearing movement of the rock, as generally conceived, it must be generated slowly, and hence would probably be dissipated nearly, if not quite, as rapidly as it is produced.

As the ellipsoids became more and more flattened the interstitial pyroxene bands would assume a parallel arrangement, as in the case of other similar gneissoid structures.†

In support of the hypothesis of dynamic origin we note:

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* J. G. Goodchild: Geol. Mag., new series, Dec. IV, vol. I, no. 1, Jan., 1894, p. 23.

† F. Zirkel: Lehrbuch der Petrographie, band iii, p. 205.

1. The gneissic character of the microstructure as traced from the coarse grained through the ellipsoidal to the streaked varieties. The augen-structure represented in specimen number 160 is clearly typical of the results usually credited to dynamic movements. Inasmuch as this appears to be merely a special development of a portion of the rock having little or no augite, it would not seem unwarranted to infer that the agencies operating here affected other portions of the rock as well, and hence that the development of the gneissic structure was in both cases referable to the same agencies.

2. The evidence of recrystallization of the granular areas. This appears not only in the irregular interlocking outline of adjacent grains, but the frequent presence of fresh plagioclase feldspar as a cement for the other constituents and the development of hornblende in idiomorphic forms in the more gneissoid rock.

3. The indication of dynamic action as shown (*a*) by the fracturing of the augite and microcline grains, and (*b*) the indication of strain appearing in the bending of the microcline lamellæ, accompanied by undulatory extinction and the development of polysynthetic twinning of the pyroxene. These phenomena are chiefly confined to the coarse grained rock, and even here are not pronounced. It may be that some of them are due to movements subsequent to the development of the gneissic structure. The appearance of strain in the microcline, however, in certain cases (page 116) seems rather to be connected with the production of the gneissic structure. This is true also in certain cases in the breaking of the pyroxene grains, but in general neither pyroxene nor microcline furnish any evidence as to what proportion, if any, of the granular materials represent fragments of the original minerals.

4. The character and relations of the inclosed apatite. The significance of these deposits lies in their generally crushed condition. The crushed appearance of the apatite is more pronounced, so far as the limited data at hand shows, in the deposits occurring in the streaked gneiss than in those in the coarser rock. In places where the gneissic structure of the rock is imperfectly developed, the crushing of the apatite likewise appears incomplete. The mass is made up of rather coarse fragments, with granular apatite filling the interstices. In some cases (page 107) the mass is intersected by thin seams of feldspathic material extending in from the walls and continuous with the surrounding layer. Often the deposit is reduced almost wholly to a granular condition. These granular deposits, called sugar apatite, are sometimes of considerable extent, as noted by Professors Penrose* and Harrington.†

Professor Penrose says: "The granular variety known as sugar apatite is of a white or pale green color and looks like coarse sand, more or less coherent. * * * It is one of the purest forms of apatite mined. It is uncertain what could have caused the apatite to assume this granular condition."

Professor Harrington states that "though at some localities the apatite occurs chiefly in crystals, at others it is wholly or almost altogether massive, varying from compact or crypto-crystalline to coarse granular. Frequently also it exhibits a distinct lamellar texture. A friable saccharoidal variety is very common and often termed 'sugar phosphate.' When white it is sometimes difficult to distinguish by the eye from some forms of quartz sandstone. * * * Crystals are sometimes imbedded in this granular apatite, and frequently also rounded masses of apatite

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*R. A. F. Penrose: Bull. 46, U. S. Geol. Surv., p. 38.

†B. J. Harrington: Geol. Survey of Canada, p. 14 G.

up to many inches in diameter. Similar masses of pyroxene as well as crystals are also sometimes imbedded in the apatite."

It is also worthy of note that the form of the deposits in both gneiss and pyroxenite is strongly suggestive of crushing and squeezing. This was remarked by Harrington,* who says: "The apatite masses look as if they had been driven or squeezed into the curious forms which they now present during the folding or crumpling of the enclosing rock."

The explanation of the large apatite crystal (pages 103, 127) in the leopard rock is not without difficulty. One or two instances only were observed and we have no information that they ever occur in the streaked gneiss. From the manner in which the ellipsoids and bands of the gneiss arrange themselves concentrically about the apatite, it is clear that the crystallization of the apatite took place prior to the development of the gneissic structure.

Four views may be suggested to account for the apatite crystal in its present position:

1. That it crystallized out of the original magma before the solidification of the latter. From the relations of both the crystallized and granular deposits of apatite occurring in the syenite-gneiss, it is evident that an explanation that will account for the presence of one must apply also to the other. We have considered already the objections to the view of the formation of these deposits in the original magma (page 127). These are the large size of the crystals, their inclusions and rounded outlines, and the extent and more or less crushed condition of the deposits.

2. That it is due to segregation and crystallization after the solidification of the rock. The belief is expressed by Harrington in the report above cited that in many cases there has been a segregation of apatite and other minerals which accompany it from the surrounding rock into irregular or lenticular masses without any true cavity or crevice having ever existed. The growth of crystals by replacement in situ has been noted by various observers.†

Indications of such development appear in the small hornblende crystals occurring in the streaked gneiss, as described in another part of this paper (page 118). The development of large crystals by this process, however, has not been demonstrated and is considered improbable.

3. The third view is that they were deposited in a cavity in the syenite prior to the development of the gneissic structure. The objection to this hypothesis lies in the difficulty of accounting for the obliteration of the cavity without crushing the apatite. It may be supposed that the cavity was large in proportion to the size of the crystal and did not become closed at once but gradually, and that by the time the walls had closed in, the surrounding rock had become sufficiently plastic to adjust itself about the crystal without breaking it. The objections to the view that the rock had reached such a condition of plasticity have been considered (page 130). Moreover, the former presence of a cavity should be indicated by an irregularity in the arrangement of the ellipsoids about the apatite, which does not appear to be the case, though the observations upon this point were not conclusive.

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* B. J. Harrington: Geol. Survey of Canada, Report G. p. 7.

† C. R. Van Hise: Am. Jour. Sci., 3d ser., vol. 33, 1887, p. 385.

4. The fourth view, and probably the correct one, is that the apatite was formed in cavities in the pyroxenite, and that it became inclosed in the syenite during the intrusion of the latter. The objection to this view, as in the preceding, lies in the difficulty of accounting for the preservation of its crystallographic form. However, as the ellipsoidal rock evidently represents an early stage in the development of the gneissic structure, it is probable that the differential movement at this point was not so great but that the crystal was able to withstand the strain.

SIMILAR STRUCTURES IN OTHER ROCKS.

Analogous structures in mica-gneisses are well known. A variety called stengeliger-gneiss (wood-gneiss), according to Zirkel,[*] is characterized in some cases by bands of mica winding about the stalk-shaped or wreath-shaped feldspar-quartz masses, so that these are inclosed on all sides by the mica layers. On cross-fracture, therefore, these will show discoidal, ellipsoidal, elongated, roundish, trapezoidal figures formed by the mica bands. Up to this point the description applies very well to the Ottawa occurrences, except in the character of the mineral forming the bands. Beyond this, however, the analogy fails, as further alteration produces an asbestos-like structure which has no counterpart in the rocks under consideration.

Rothpletz has noted[†] a structure analogous to that here described in the greenstone-schists (actinolite-schists) of Hainchen, and Williams[‡] from northern Michigan. Both of these observers ascribe it to brecciation in situ, while the former explains the rounded character of the fragments and the production of much of the interstitial material by the rubbing together under the action of much orographic pressure of a mass already finely subdivided by cracks. Lawson has described similar occurrences in the Lake of the Woods region.[§]

CONCLUSION.

Reviewing now the different hypotheses in the light of all the evidence available, it is apparent that no one of them seems to offer a full and adequate explanation. The ellipsoidal and the gneissic structure in these rocks are clearly closely related in origin, and any conclusion affecting the one has a direct bearing upon the other. Our knowledge of the processes by which the ancient gneisses were formed is extremely limited. That they may be formed by dynamic processes has long been recognized, and it is now well established that a laminated structure comparable to that of the gneisses may be produced in deep-seated igneous

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[*] Lehrbuch der Petrographie, band iii, p. 203.

[†] Zeitschrift der deutsch geology Gesell., vol. 31, pl. ix, x, 1879, pp. 374–397.

[‡] Bull. 62, U. S. Geol. Survey, 1890, pp. 166–177.

[§] Geol. and Nat. Hist. Survey of Canada, Ann. Rep., 1885, Rep. CC, p. 51.

rocks as the result of the conditions attending their intrusion. In consequence of the constitutional changes which appear to take place in rocks when subjected to great orographic pressure, it becomes in many cases extremely difficult, if not impossible, to distinguish between the two kinds of gneisses. Moreover, our knowledge of the cause of differentiation of igneous magmas is as yet little more than a speculation, but that the nature of this original differentiation conditions in part the character of the structure resulting from subsequent processes is obvious.

While in many respects incomplete, involving, as it does, much that is as yet little understood in the metamorphism of rocks, on the whole the evidence seems to favor the last hypothesis (V), namely, that of dynamic metamorphism.

Briefly summarized, this hypothesis supposes—

1. That the structure characterizing the leopard rock is due to orographic agencies and represents an intermediate stage in the development of a streaked augite-syenite-gneiss out of an augite-syenite which was distinguished by a coarsely crystallized structure and by a somewhat irregular aggregation of pyroxene. The character of the original magma may have been modified somewhat by the absorption of included fragments of pyroxenite.
2. That the distribution of the pyroxene has been effected presumably by the solution of portions of the original constituents and their recrystallization along lines marking the location of the cracks.
3. That with continued pressure these lumps have been more and more drawn out, the process being accompanied by recrystallization until the rock assumes the streaked gneissoid form.

While in general the evidence of crushing is rendered more or less doubtful by the extent of recrystallization, in one case (number 159) it is undoubted. This represents a partly developed gneiss in which, however, the ellipsoidal structure is but imperfectly presented. Though differing considerably from the rest of the rock in general appearance, there is little doubt but that it belongs to the same mass. The groundmass is much finer than in any of the others and shows much less the effects of recrystallization. Large grains of microcline are partly crushed and drawn out into lens-like forms comparable to the augen-structure. A significant feature is the arrangement of the augite in irregular bands about the feldspar and quartz. In some of the augite grains the appearance of crushing and dragging is pronounced, while the general appearance of the rock, both in hand specimens and under the microscope, admits of no other conclusion than that its present structure is due to the effects of orographic pressure.

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STUDIES OF *MELONITES MULTIPORUS*[*]

BY ROBERT TRACY JACKSON AND THOMAS AUGUSTUS JAGGAR, JR

(*Read before the Society August 27, 1895*)

CONTENTS.

INTRODUCTORY.

The remarks in this prefatory statement will serve as an introduction for the present paper on *Melonites multiporus* under joint authorship, and also for the succeeding paper, "Studies of Palæechinoidea," by myself.

Deep obligations are due to Mr Alexander Agassiz for the opportunity of studying the rich collections of Paleozoic echinoderms in the collections of the Museum of Comparative Zoölogy at Cambridge. Besides an extensive series of *Melonites multiporus*, this museum possesses a number of generic and specific types and many rare species, as described in the following pages.

For the opportunity of using material, obligations are also due to Professor R. P. Whitfield, of the American Museum of Natural History in New York; Professor C. E. Beecher, of Yale University Museum; Mr C. Schuchert, of the United States National Museum; Professor A. Hyatt, of the Boston Society of Natural History; Professor William B.

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[*] Plates and descriptions of the same, also list of references quoted, will be found at the end of the succeeding paper: Studies of Palæechinoidea. References are indicated by a figure in parenthesis after names of authors cited.

Clark, of Johns Hopkins University; Mr C. W. Johnson, of the Wagner Free Institute, and Professor W. B. Scott, of Princeton.* Similar privileges were extended to Mr Jaggar by Dr E. Newton, of the Museum of Practical Geology, in Jermyn street, London. To my friend, Professor Beecher, I am indebted for critical suggestions. Professor Whitfield and Mr Johnson very kindly had drawings made for me.

Sincere thanks are due to Mr J. H. Emerton, of Boston, for the extreme pains he took in making the drawings for the plates. Each individual plate in a specimen was carefully scrutinized to ascertain its relative size and angles, all peculiar plates, the position of columns, etcetera, were measured, and all were drawn with great accuracy. No portions of specimens as figured are restorations except in the cases where specially stated and indicated by dotted lines or shading in the figures.

Mr Jaggar, while working with me as a student in the Geological Department of Harvard University, made the very important discovery of the regular arrangement and progressive introduction of plates in the interambulacral area of *Melonites multiporus.* His observations were based on the specimen illustrated by plate 3, figure 12, and plate 4, figure 18, which was at that time in the Student Paleontological Collection. Mr Jaggar compared this arrangement with that of *Oligoporus danæ*, as shown in Meek and Worthen's figure, introduced here as figure 34 of plate 6. He also studied the spines of *Melonites multiporus.* Mr Jaggar had not the time nor the opportunity to carry the results of his observations further. In London, at the Geological Museum in Jermyn street, he made drawings of *Palæechinus*, which are reproduced in plate 7, figures 38 and 39. I have carried on the studies of the interambulacrum of *Melonites multiporus*, extending it by observations on other specimens. I have also added the studies of the ambulacral area in this species. In the succeeding paper, "Studies of Palæechinoidea," the researches begun in *Melonites multiporus* are extended to other species and genera.

ROBERT TRACY JACKSON.

DESCRIPTION OF SPINES.

The spines of *Melonites multiporus*,† Norwood and Owen, have not been previously described, though their general character has been suggested by analogy to related species and genera and by the minute sur-

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* Many of the specimens described came from Ward's Natural Science Establishment at Rochester, New York.

† As a matter of information worthy of record, it is stated where the types of Paleozoic echinoids described in this and the succeeding paper are deposited. The specimens of *Melonites multiporus* figured in the Illinois Geological Survey, vol. ii, pages 227 and 228, are in the A. H. Worthen collection, which is now in the University of Illinois, at Urbana, Illinos, as I am informed by Mr William F. E. Gurley, state geologist of Illinois. These specimens and many types are included in a published list of the Worthen collection.

face tubercles which thickly cover the plates of the test in occasional well preserved specimens. The spine tubercles of this species were figured by Roemer (36), and are present in great numbers on the specimen from which plate 4, figure 12, was drawn, and by careful examination these tubercles can be seen in portions of the photographic figure (plate 5, figure 18). They served as bases of articulation for hundreds of small spines which covered thickly both the ambulacral and interambulacral areas.

The specimen showing spines from which plate 2, figure 1, was drawn is a single individual of *Melonites multiporus* from the Saint Louis group, Subcarboniferous of Saint Louis, Missouri. It is in the collections of the Museum of Comparative Zoölogy (catalogue number 2988). The specimen is of the usual type from this locality; close inspection, however, reveals scattered over the test, but more especially in the protected furrows and depressions, innumerable minute spines clinging to the plates of both the ambulacral and interambulacral areas. They are most abundantly and best preserved in the longitudinal furrows formed by the depressed, irregular, lateral plates of each ambulacrum. A cluster of these spines is shown in plate 2, figure 1, magnified 6 + diameters. The well preserved spines are cylindrical, somewhat swollen at the base, and gradually taper to the distal point. Occasional very well preserved spines, however, show surface ornamentation, which consists of successive faint swellings, interrupted by constrictions, that give to the spine a beaded appearance, as shown in the figure. This surface ornamentation was first observed by Mr Westergren when drawing the accompanying figure. The dimensions of the spines are, average length 3 millimeters, maximum thickness at the base 0.4 of a millimeter, and from this tapering to a somewhat blunt end at the distal terminus.

The spines are frequently broken or reduced in size by erosion; but otherwise all have approximately the same length on both ambulacral and interambulacral areas. On the interambulacra they are so much more exposed that by far the greater part of the spines are short and stubby from erosion. Only occasionally a long spine equalling the length of those in the ambulacra is found; but there are enough of these to fully warrant the statement that the spines of both areas were of the same length. None of the spines of the interambulacra were seen showing the bulgings described, but this is attributed solely to erosion, for such ornate spines were only found in well protected areas. Besides the specimen figured, another specimen of *Melonites multiporus* in the Museum of Comparative Zoölogy (catalogue number 2996) shows spines. The features exhibited do not differ from those just described. Spines have also been observed on two other specimens.

Hambach (18) has published a photographic figure of *Melonites crassus*, Hambach, which shows numerous spines.' In the description it is stated that the ambulacral areas are covered with little spines about one-eighth of an inch in length, while the spines of the interambulacra are only one-half as long. This peculiarity Professor Hambach refers to as one of the points of specific distinction from *Melonites multiporus*, which indicates that he was familiar with the spines of that species. This distinction of the two species is noteworthy, inasmuch as M'Coy's (29) distinction of his family of the Palæechinoidea is based largely on the uniformity of the spines as distinguished from the two series present in the Archæocidaridæ. As stated above, only a very few spines of the interambulacra of *Melonites multiporus* were found of the same length as those in the ambulacra. It is possible, therefore, that in Professor Hambach's specimen of *Melonites crassus* all the spines of the interambulacra were so eroded as to give the impression that they were really shorter than those of the ambulacra. This could easily happen, and it is the only species of the Melonitidæ in which such a difference is noted.

Besides the foregoing, the spines of American Melonitidæ have been described by Messrs Miller and Gurley (34) in *Melonites indianensis*, Miller and Gurley, and *Oligoporus bellulus*, Miller and Gurley. In the succeeding paper the spines of *Oligoporus danæ* are described (plate 6, figure 32).

ARRANGEMENT AND DEVELOPMENT OF THE AMBULACRAL AND INTERAMBULACRAL PLATES.

The next subject to which attention is called is the regular arrangement and method of introduction of the plates of the ambulacral and interambulacral areas in the Melonitidæ. The arrangement of the interambulacra has been partially figured in *Oligoporus danæ*, M. and W., and appears fragmentarily in a number of published figures of *Melonites*, *Palæechinus*, and some other genera of Palæechinoidea, but its significance and true relations seem to have been quite overlooked.

Roemer (36) supposed that the intercalated columns terminated in much the same way at either end. He says: "Die Vermehrung der Reihen von den Polen gegen die Mitte der Schale hin geschieht durch allmähliches Einsetzen neuer Reihen zwischen die vorhandenen."

Lovén (25) says of the Perischoechinoida that the adambulacral plates alone extend from the peristome to the dorsal pole, which observation is entirely supported by the results of our studies.

Miller and Gurley (34) consider briefly the method of growth of *Oligoporus blairi*, Miller and Gurley. They express tentatively the belief that the number of columns of interambulacral plates does not increase with growth, but their view as expressed is quite the opposite of our conclusions. This view was based on 3 specimens studied, all of which they state have 6 columns of plates. The answer would be that while the number of columns apparently does increase with age, the full number may be attained quite early in the life of the individual.* In such a case a considerable increase in size may take place without the addition of any new columns. These are the only statements seen in regard to the arrangement of interambulacral plates in Palæechinoids, except the general remark frequently met with, that the columns (ranges) of plates fail to reach the poles.

Before describing the plate arrangement in detail it may be well to state the case in brief. Echinoderms grow by the addition of new plates to the corona around the abactinal area and by the increase in size of previously formed plates. As the new plates of each ambulacrum or interambulacrum are formed they are inserted between previously formed plates of the area and the genital or ocular plates (see plate 3, figure 13); therefore those plates on the lower part of the test were the earliest formed, and passing dorsally we get progressively the later and later added plates, built as the individual grew aborally.

In *Melonites multiporus*, at the oral termination of the corona and in immediate contact with the peristome, each ambulacrum has a row † of four plates and each interambulacrum a row of two plates ‡ (plate 2, figures 2 and 3). Passing from this part progressively upward, or dorsally, we find an increase in the number of columns in both the ambulacra and interambulacra. In the ambulacra the two outer plates at the base, *a*, *b*, with additions dorsally, form the two lateral columns of the area, and the two median plates at the base, *a′ b′*, with additions dorsally, form the two median columns of the area (plate 2, figure 4, and plate 4, figure 18). In the interambulacra new plates are added to form each column, and also new columns are added with great regularity (plate 2, figure 2; plate 3, figure 12; plate 4, figure 18). New columns are added rapidly at first, and they attain their greatest number at a point of somewhat variable distance above the ambitus (plate 4, figure 18).

Near the anal area the number of columns of interambulacra decreases as well as at the oral area, but for a different reason, as discussed. In the figures the several columns are numbered progressively, corresponding to the number of columns attained by the individual, and therefore

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* See figure of *Palæechinus gigas*, plate 7, figure 38.

† The term *row* in this paper is limited in use to series of plates lying in one horizontal plane, in contradistinction to the term *column*, which is applied to series of plates lying in a vertical plane.

‡ The structure and development of the ambulacrum and the position and development of the first three interambulacral columns, numbers 1, 2, 3, plate 2, figures 2, 3, etc., as described in this paper, were worked out by R. T. Jackson.

will be readily followed. It is to be observed that successive columns, passing dorsally, are typically alternated to the right and left of one another (plate 3, figure 12; plate 4, figure 18). This rule has some exceptions, principally in even-numbered columns, but occasionally in odd ones. It will be seen that the plates of the adambulacral columns are pentagonal, while all the other plates of the interambulacral areas are hexagonal, with the exception of the ventral terminal plates of columns which are pentagonal* and adjacent plates which are in most cases heptagonal; also near the anal area the plates, instead of being hexagonal, are more or less rhombic in form (plate 3, figure 13).

The arrangement as sketched above has been traced in more than 100 specimens of *Melonites multiporus*, and in all the same method of introduction and growth is maintained, with only such slight variations as are discussed. A similar arrangement has also been traced to a greater or less extent in *Rhoechinus*, *Palæechinus*, *Oligoporus*, *Lepidechinus*, *Lepidocentrus*, *Lepidocidaris* and *Archæocidaris*, and in a published figure of *Lepidesthes*, as described in the succeeding paper. It may be stated that no conflicting evidence has been found in any Paleozoic or recent type.

STRUCTURE AND DEVELOPMENT OF THE AMBULACRUM.

Turning to the detailed description of plates, the oral area will be considered first. Specimens showing perfectly the oral termination of the corona seem to be rare, for that area has never been adequately described, and most specimens which are at first sight complete are wanting in one or more rows of plates. A specimen showing this area satisfactorily is a *Melonites multiporus*, Norwood and Owen, from the Saint Louis group, Subcarboniferous of Saint Louis, Missouri.† The specimen is in the collections of the Museum of Comparative Zoölogy (catalogue number 3000), and is represented in plate 2 by figure 2. The ambulacra ventrally in each area consist of a row of four plates which lead to perpendicular columns by the addition of plates dorsally. The plates at the ventral termination as well as the later added ones have two pores. In each area, as also observed on many other specimens, the two outer initial plates, *a b* (plate 2, figure 4; plate 4, figure 18), become the bases of the two lateral columns of the ambulacrum, and the two middle initial plates, *a′ b′*, become the bases of the two columns of large median ambulacral plates. At the ventral area all the ambulacral plates are of about the same size and shape, whereas further up the plates of the two central columns, *a′ b′*, are much larger than the plates of the lateral columns

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*Excepting the initial plate of column 3. See plate 2, figures 2 and 3.

†All the specimens of *Melonites multiporus* described in this paper are from the same formation and locality; therefore no further details on this point will be given.

of the area; the central columns of plates also are quite regular in size and form, whereas the laterals are highly irregular, as shown in plate 2, figure 4; plate 4, figure 18. The curvature of the surface of the ambulacra, which gives the melon-like ribs, is not existent at the ventral area. This and the other characteristic generic features of this area were not developed in that portion of the test which lies near the peristome.

Besides the four columns, *a*, *a′*, *b′*, *b*, which are found already at the peristomal border, new columns of ambulacral plates are added dorsally as the animal grew. The new columns are added in the two lateral depressed furrows of each ambulacrum, and in each case between the lateral and median columns of the side to which it belongs, as seen in plate 2, figure 4, and plate 4, figure 18. In our specimen, as shown in the figure (plate 2, figure 4), the first new columns added, *c* and *d*, originate at about the same horizon in each half ambulacrum. The fourth columns of each area as added, *e* and *f*, again originate at the same point in the two sides of the ambulacrum. The number of columns in the ambulacra increases rapidly, but the plates of the ambulacral area are so irregular and usually so imperfectly defined that they are difficult to make out, and only a few specimens have been seen in which the development of this area could be satisfactorily traced. Besides figure 4, the development of the ambulacrum and the introduction of its newly added columns are shown well in areas *B*, *D*, and *F* of figure 2, plate 2.

A section of the ambulacrum of *Melonites multiporus* (plate 2, figure 5) shows the relative size, thickness and position of the several columns of ambulacral plates. The specimen is quite normal in form, not being at all distorted. The adambulacral plates *I I* of adjacent interambulacral areas project under the lateral plates *a b* of the ambulacrum, not over them, as they do in *Lepidocentrus.* The median plates *a′ b′* of the area are very thick, as well as large in other proportions. The pores in the ambulacral plates on the surface or distal side lie in that portion of the plate which is nearest the interambulacrum (figures 4 and 5), but in traversing the thickness of the plate they extend inward or toward the center of the area, as shown in figure 5. In this section plate *X* was cut in such a plane that the pores did not show. Some of the pores in the section are seen passing quite across the plate. When their whole extent is not visible, their probable position is indicated in the figure by dotted lines.

The position which new columns take as introduced in the ambulacra in relation to the initial columns *a a′* and *b′ b* is important, especially in connection with the condition seen in *Oligoporus* as discussed in the next paper under the consideration of that genus. The four initial columns of *Melonites* can properly be homologized with the four columns seen in adult *Oligoporus* (plate 6, figure 30), and this is important, because the difference of the number of columns is the basis of separation of the genera. As *Melonites* ventrally has ambulacra like adult *Oligoporus*, and as adult *Melonites* has much more complex ambulacra (plate 5, figure 20), it may be considered that *Oligoporus* is the more primitive genus and *Melonites* the more specialized, being further advanced in the special line of variation of the family. *Melonites* may be considered as highly accelerated, for at an early period in development where *Oligoporus* (plate 6, figure 25), has but two plates in the ambulacrum, *Melonites* has four. The four initial columns of *Melonites*, *a a'* and *b' b*, are together equal to the two columns of plates of less specialized genera, as the primitive Silurian type *Bothriocidaris*, and also *Archæocidaris*, *Cidaris*, etcetera. This relation is discussed in the succeeding paper under *Oligoporus* ("Arrangement and Development of Plates in *Oligoporus coreyi* "), and is expressed in a diagram, figure 1, inserted in the text at that place.

The late honored Professor Sven Lovén (27) has shown in modern echinoids that a considerable number of the ventral plates of the ambulacrum are resorbed during the progressive enlargement of the actinostome. More or less of this resorption has also probably taken place in the growth of *Melonites*. These missing plates could only be obtained in very young specimens. If present, they might show that the ambulacrum in its inception had only two plates in a row, instead of four. This would be in accordance with the earliest stages of *Oligoporus*, of modern echinoids, and also with the condition of the adult in the ancient primitive type *Bothriocidaris* and most members of the Palæechinoidea.

STRUCTURE AND DEVELOPMENT OF THE INTERAMBULACRUM.

The interambulacra of the adult, when perfect, consist of two plates at the ventral termination, as shown in three areas, *A*, *C* and *I*, of plate 2, figure 2. These plates, numbers 1 and 2, are pentagonal in form, having a straight line on the ventral aspect. It is to be noted that the angles of these plates do not correspond to the angles of terminal pentagons in later added columns, as seen in this and other figures. These two first ventral plates give rise, by the progressive addition of plates dorsally, to the two outer columns of pentagonal adambulacral plates. In two areas, *E* and *G* of our specimen (plate 2, figure 2), there are three plates at the termination of the interambulacra. It will be observed that these plates have angular faces ventrally, corresponding to the angles of the ventral border of the second row in an area terminating ventrally in two plates (see also plate 2, figure 3). It is evident, therefore, that the lower row of two plates is absent from mutilation in these cases, which at first sight apparently terminated in three plates. This is an important point, for quite frequently specimens of *Melonites multiporus* are seen, showing three plates ventrally. Such areas are to be considered incomplete ventrally, and when well preserved show at the oral termination angles for the articulation of the lowermost missing row. Another evidence of the limits of the area ventrally is a line, *M*, of thin, dark colored, calcareous tissue, which runs around the outer border of the peristome, coinciding with the ventral edges of the plates. This apparently is the ventral border of the perignathic girdle, or the auricles and other perpendicular calcareous supports on the edge of the peristome for the attachment of buccal muscles. This line of tissue stands out clearly in the open space if the lowest row in any area is wanting, as between the areas *C* to *H*, inclusive (plate 2, figure 2). This perignathic girdle has only been observed in this specimen. Besides the specimens figured, the ventral termination of the interambulacra in two plates has been seen in a number of other specimens of *Melonites multiporus*, amounting to 21 areas in all. In specimen number 3003, in the collections of the Museum of Comparative Zoölogy, there are two plates at the ventral termination in all five interambulacral areas, as shown in plate 2, figure 3. These plates are succeeded by three plates in the second row. The same specimen shows well the ventral termination of the ambulacral areas as seen in the figure. Two specimens from the Boston Society of Natural History (catalogue numbers 229A and 229B), also specimens in the E. M. Museum at Princeton (catalogue numbers 1464 and 1466), show two plates ventrally in several areas.

This fact of two ventral plates is important because of the similar number of columns of plates in the Euechinoidea. It is also important as compared with the number of plates seen ventrally in other Paleozoic echinoids (*Oligoporus*, *Lepidechinus*, *Archæocidaris*). Its special bearing is the fact that it shows the limits of the encroachment of the peristome on the corona of this genus, which may be taken as the type of the family.* The extent of encroachment varies in different types from not at all, *Bothriocidaris*, *Lepidechinus*, to an extensive encroachment, *Archæocidaris*, *Cidaris* (see figures 42, 43, 44, 48 and 55 in the plates).

The only published observations seen on the extreme ventral area of *Melonites* is Meek and Worthen's (30) figure of the ventral aspect of *Melonites multiporus*, showing the jaws in place. In the text they do not describe or discuss the plates, but in the figure the five ambulacral areas show four plates at their ventral termination. One of the interambulacra has two plates ventrally, three have three plates, and one has five. This discrepancy with our observations is unquestionably due to imperfections of the specimen figured, not to variations in this important feature.

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* See classification at end of succeeding paper: Studies of Palæechinoidea.

Before describing further the plates of *Melonites* it is desirable to consider whether the lower row of two plates, numbers 1 and 2, plate 2, figures 2 and 3, really represent the first formed or initial interambulacral plates.

Professor Sven Lovén (27) has shown that at the ventral border of the interambulacra in the young of *Goniocidaris** and *Strongylocentrotus* there is but a single plate which in the next row is succeeded by two plates (plate 3, figure 8). At the same period of growth the ambulacra have two columns of plates as in later stages. Of this, Professor Lovén says, "This is the normal constitution of the peristome in the whole class." He shows that during later growth with the enlargement of the actinostome that area commonly encroaches upon the corona, and the initial plate is gradually resorbed (plate 3, figure 9), and as the encroachment of the actinostome continues, some succeeding binary plates are also resorbed together with the corresponding portions of the ambulacra. In the Clypeastroids and Spatangoids the initial single plate is typically retained throughout life, as shown in numerous figures published by Lovén (25), A. Agassiz (3), William B. Clark (6), and Duncan and Sladen (10).

It is obvious that the enlargement of the actinostome may take place by resorption of the plates of the base of the corona or by the progressive growth of the same, both tending in the same direction, the enlargement of the ventral circumference. *Tiarechinus* from the Trias is a genus which retains the initial single interambulacral plate, and so does *Lepidechinus* (plate 7, figure 42) and *Pholidocidaris* (plate 9, figure 54).

From the above we gather the conclusion that resorption of ventral plates may or may not take place, and that the interambulacrum probably always starts with a single plate. If Lovén is correct in supposing that the interambulacrum always terminates with a single plate, as every evidence goes to prove, then *Melonites* when young must have had a single plate at the ventral border.

In a specimen of *Melonites multiporus* in Yale University Museum (diamond number 157, specimen C) we find an important feature bearing on the above consideration. In this specimen (plate 3, figure 10)† the two ventral plates have each an angle toward the median line, and these, together with the straight edge of the bottom, enclose a triangular space which doubtless contained the single initial plate, as in a similar stage of *Strongylocentrotus* plate 1′ (plate 3, figure 9). This specimen of *Melonites* does not actually show the initial single plate, and obviously

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* A reproduction of Lovén's figure of this genus is given as an insert, figure 3, in the chapter entitled "Conclusions" of the succeeding paper: Studies of Palæechinoidea.

† In the specimen, plates 2 and 3 (see figure) have slipped down a little from their original position, but they are restored to their places in the figure as they could be, all the angles being preserved, by simply moving them upward.

in its peculiar position it would very easily drop out after the death of the individual or in the processes of fossilization.* To our mind the angles for its reception are almost as strong evidence as the plate itself; so it may be confidently stated that the interambulacrum of *Melonites* originates with a single plate, as shown by Lovén in *Goniocidaris* and *Strongylocentrotus*, and in the succeeding paper in *Lepidechinus* and *Pholidocidaris*.

The specimen represented by figure 10, plate 3, evidently indicates a condition in which some resorption of the ventral border of the corona has taken place, and would correspond closely to the same condition in *Strongylocentrotus* (plate 3, figure 9). Reconstructing the ventral plate of *Melonites* to the condition it probably had before resorption cut into its ventral border, we have the condition shown in plate 3, figure 11, which is an adaptation from the ventral area of interambulacrum A in plate 3, figure 2. In this reconstruction of *Melonites* we have a ventral plate 1′ comparable to that seen in *Strongylocentrotus* before ventral resorption has commenced (plate 3, figure 8); also as seen in *Lepidechinus* (plate 7, figure 42) and *Pholidocidaris* (plate 9, figure 54).

The single plate found at the ventral border of the interambulacrum in echinoids, as shown by Lovén in the young of modern forms and here in Paleozoic forms, points directly to the conclusion that this stage in growth represents an ancestral form having a single column of interambulacral plates. The only such form known is the Lower Silurian genus *Bothriocidaris* (see figure 4 of the succeeding paper, in the chapter "Conclusions"), which from this fact assumes the greatest importance. In *Melonites* we show that newly added columns normally alternate to left and right as introduced, even-numbered columns typically appearing on the right of odd ones (plate 2, figure 2; plate 3, figures 12 and 14, and plate 4, figures 18 and 19). This being the case, it seems fair to argue that the initial plate 1′ of *Melonites* (plate 3, figure 11) was the basal member of column number 1, the left adambulacral, column 2, being introduced to the right of it. This assumption would carry with it the conclusion that the left adambulacral column of *Melonites* and allies is probably the genetic equivalent of the single column of *Bothriocidaris* (figure 4 of succeeding paper).

Returning to the consideration of the interambulacrum of *Melonites multiporus*, in the next row above the ventral plates 1 and 2 (plate 2, figure 2) there are three plates. The median plate, number 3, is hexagonal in form, and it is the first formed plate of a new column; it makes, with the addition of new plates dorsally, the first column of median hexag-

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*Similar angles in the two ventral plates are shown in *Oligoporus* (plate 6, figure 26), and the initial plate is shown in *Lepidechinus* (plate 7, figure 42).

onal plates, as seen by following the dotted lines in the figure. Initial plate 3 is hexagonal in form; but, comparing it with the initial plates of later added columns (plate 2, figure 2), it will be seen to be similar in form ventrally and on the two sides. It is potentially pentagonal, if we may be allowed the expression, but is hexagonal because its dorsal border is truncated by the impinging ventral border of the terminal pentagon, number 4 of column 4. The terminal pentagon always induces by impact an additional side on one of its ventrally bordering plates, as seen in later added columns, and in this case it thus makes a hexagon out of a plate normally pentagonal. Plate 3 is typically hexagonal, and exceptions to this form are very rare. Column 3 at its point of origin is obviously central in position, having a column of lateral adambulacral plates on either side. In the next row dorsally there are four plates, pentagon number 4 being the initial plate of column 4. The ventral aspect of this pentagon impinges on plate 3, causing it to take on a hexagonal form as just discussed. In four areas of the figure, A, C, E and G, column 4 at its point of origin has two columns on the left of it and one on the right; in a fifth area, I, the reverse obtains, there being one column on the left and two on the right. This shows at the start a variation which is not infrequent in even-numbered columns. Another case of the same kind is shown in the introduction of column 6 in area G of the same figure. Here there are two columns on the left and three on the right, whereas in the two other areas, E and I, showing the introduction of the sixth column, there are three columns on the left and two on the right. While even-numbered columns in most cases originate to the right of the center, having one more column on the left than on the right, they sometimes originate to the left of the center, having one more column on the right than on the left. Other examples of this variation are seen in plate 3, figure 10, and in the tables on pages 165 to 170, inclusive.

Later stages, with new columns added after the fourth, might be traced in plate 2, figure 2, but they can best be followed by comparison with the description of stages represented by figure 12 of plate 3. It will be seen in plate 2, figures 2 and 3, that columns 3 and 4 are introduced very early in passing from the ventral area dorsally. This rapid introduction is also shown well in *Melonites giganteus*, sp. nov. (plate 5, figure 21). It is the common condition, but exceptions may be found, as in plate 3, figure 12, where column 4 originates much later than column 3. The rate of introduction of new columns, as shown in plate 2, figure 2, may be accepted as the average rate in *Melonites multiporus*, to which we have seen but two exceptions, namely, those shown in plate 3, figures 12 and 16. The rapid introduction of the new columns 3 and 4, in plate 2, figure 2, shows an accelerated development which is still more accentuated in

Melonites giganteus (plate 5, figure 21), where the fifth column originates in the second row above the fourth. On the other hand, the relatively later period of introduction of column 4 in the two examples of *Melonites multiporus* seen (plate 3, figures 12 and 16), shows a tendency toward a slower rate of development. In *Tiarechinus* we have a case of even greater accelerated development, for in it, according to figures by Professor Lovén (26), there are three plates in the second row succeeding the initial single plate of the first row.

One of the clearest examples of the method of plate arrangement seen is a specimen of *Melonites multiporus* in the collections of the Museum of Comparative Zoölogy (catalogue number 2990).* Plate 3, figure 12, represents the interambulacral area of this specimen, which is also shown in the photographic reproduction (plate 4, figure 18), and the nature of the plate arrangement may be seen by following up the series of columns of plates which are accentuated by dotted lines. While not complete dorsally or ventrally, this specimen is very clear and is also very typical, showing little departure from the ideal type of plate arrangement.†

Starting at the ventral end of the specimen (plate 3, figure 12, and plate 4, figure 18) there are three columns of plates, composed of two adambulacral columns of pentagonal plates, numbers 1 and 2, and a median column of hexagons, number 3. This middle column, number 3, would drop out near the oral termination of the area if it were complete, as in plate 2, figure 2. Passing dorsally, a new fourth column of plates is added. This column is introduced by the terminal pentagonal plate, number 4. The introduction of this plate has disturbed the mechanical form of adjoining plates, so that they are somewhat distorted, as shown in the figure, and a hexagonal plate exists at A in place of one of the lateral pentagons of column 1. This introduction of an additional side to plate *A*, making a hexagon out of a lateral plate which is normally pentagonal, seems to be an individual peculiarity of this specimen, for in the case of other interambulacral areas in which the introduction of the fourth column has been observed, the initial pentagonal plate abutted against the initial plate of column 3, inducing an additional side on the dorsal border of that plate, as in plate 2, figure 2. In one other case observed (plate 3, figure 16), the initial plate of the fourth column did not

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* This is the specimen on which Mr Jaggar based his observations of the development and arrangement of the interambulacrum.

† Its principal departure is in the slow rate of addition of columns 4 and 5 (compared with plate 2, figure 2). Initial pentagon 4 is introduced considerably later than initial pentagon 3, instead of in the next row, as in the figure cited. In area *C* of the same specimen, however, as shown in plate 4, figure 18, the fourth column begins in pentagon 4 at a very much earlier stage of growth than in area *A*. This different rate of development in two adjacent areas is uncommon and has never been seen in any other specimen in the early added columns.

impinge upon initial plate 3 because of the intercalation of a peculiar plate in column 3.

Column 4 of plate 3, figure 12, and plate 4, figure 18, is introduced as near the center as is mechanically possible with an even number of columns, but it falls to the right of the actual center, having two columns on the left and one on the right. *Melonites*, therefore, on the zone of pentagon 4 has four columns of plates, and a similar remark may be made of the progressively added columns where introduced. Continuing dorsally, especial attention is called to the intercalation of new columns, normally in regular alternation, 5 on the left of 4, 6 on the right of 5, 7 on the left of 6, etcetera. Continuing dorsally from pentagon 4, we find the fifth column introduced with a terminal pentagon, number 5. This column at its point of origin is in the middle, having two columns on either side of it. This feature is characteristic of odd-numbered columns; they have an equal number of columns on either side. Occasional exceptions, however, exist, as noted on pages 165–170. Adjoining pentagon 5, one of the plates, H, of column 4 has a seventh side added as a mechanical compensation for the form of the pentagonal plate 5. This relation of a terminal pentagon and an adjacent heptagonal plate, which is usually a member of the immediately preceding column, is characteristic of the form assumed when new columns are introduced above the fourth in the whole family of the *Melonitidæ* and in other Paleozoic echinoderms as well. Passing dorsally again, we find a sixth column introduced by the pentagon number 6, with an adjacent heptagon, H, on the left, which is a member of column 5. Column 6 at its point of origin has three columns on the left and two on the right and is therefore right-handed. Continuing still further dorsally, we find column 7, which is introduced by the terminal pentagon number 7, with an adjacent heptagon, H, on its right. The heptagon is a member of column 6. Column 7 at its point of origin has three columns on either side.

It is seen in the above that the odd-numbered columns 3, 5, and 7 are, when they originate, in the center, with an equal number of columns on either side; also it is seen that the even-numbered columns 4 and 6 are as near the center as they can be, but fall to the right of the center, with one more column on the left than on the right at their point of origin.* It is further to be noted that in the ideal case heptagonal plates fall alternately on opposite sides of the terminal pentagons in successively added columns, namely, on the right in odd columns and on the left in even columns, and are thus, when in their correct position, members of

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* In the reconstructions of the initial interambulacral plate (figures 10 and 11, plate 3) column 1 would also originate in a central position and column 2 would apparently originate with one column on the left in accordance with the above law of the method of introduction of new columns.

the preceding column to that one to which the terminal pentagon belongs (see plate 3, figure 12; plate 4, figures 18 and 19; plate 5, figure 20). This position of heptagonal plates, however, is a character which is subject to somewhat frequent exceptions, as shown in the tables on pages 165 to 170. The above may be accepted as the rule in the method of introduction of new columns in *Melonites*, *Oligoporus*, and other Paleozoic echini.

As new columns were added as the animal progressively grew dorsally,* and as new columns were introduced by a pentagonal plate, an apex of which pointed ventrally or toward the oral area (plate 3, figure 12), there is in this feature an important aid in diagnosing the relative position of the axes in even fragmentary specimens. It has been ascertained that this conclusion is correct by finding the termination of columns as stated in 14 specimens in which the axes were positively known from the presence of genital and ocular plates (plate 3, figure 13). This feature is one that has been overlooked by previous writers, for in almost all published figures of Melonitidæ, and other Paleozoic echinoids as well, in which the termination of columns is shown, the apex of the terminal pentagon points toward the upper pole of the figure, which should be the anal pole. This demonstrates that such figures were not correctly oriented, the oral and anal ends being transposed. This remark applies to Meek and Worthen's (30, 31) figures of *Rhoechinus gracilis*, *Oligoporus danæ* and *Lepidocidaris squamosus*, Hambach's (18) figure of *Melonites crassus*, and M'Coy's (28) figure of *Palæechinus sphæricus*, as well as some others.

In passing toward the anal area where the younger plates are situated, we find that there is a gradual passage from the hexagonal form characteristic of the older plates of median columns. This change of form is shown well in a choice specimen of *Melonites multiporus* which Professor Wm. B. Clark, of Johns Hopkins University, kindly loaned for study (plate 3, figure 13). It is also shown in plate 5, figure 20. In the progressively younger plates, the form is gradually modified by the progressively shorter lengths of the upper and lower sides of the hexagon until the plates have a more or less rhombic form. At this part of the test it would be more convenient to study the plates in a descending order, for the growth is properly from the early rhombic form to the mature hexagonal form. In passing from the rhombic form to the hexagonal it is occasionally seen that while the upper end of the rhomb retains its character the lower portion is truncated by a horizontal edge, thus forming a pentagonal plate with its apex directed dorsally, as in plate *P*, of figure 13, plate 3. There is, however, no need of confusing this type

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* See further discussion under "Conclusions" in the succeeding paper.

of plate with terminal pentagons of newly introduced columns. Close to the genital plates the interambulacral plates are quite irregular in form. A comparable irregularity of form in newly introduced plates may be seen in any modern echinoid, as *Strongylocentrotus.* Concurrently with the change in form, passing dorsally, there is a progressive reduction near the abactinal area of the number of columns (plate 3, figure 13). This reduction, it seems, is to be ascribed to the progressively narrowing area which the upper part of the interambulacral area presents. To make a homely simile, it may be compared to a flock of sheep coming through a narrow pass. The small number in the pass does not mean that the flock is lessening, but that no more can get through at once. We take it, therefore, that the decreasing number of plates at the dorsal end of the interambulacrum does not mean that the number of columns is dying out, but that as a mechanical matter no more plates can get through this narrow area at once. An evidence of this crowding out of columns is shown well in plate 5, figure 20. Here the separation or stringing out of successive plates of the same column is most striking. The perpendicular dotted lines will serve to indicate which plates belong to a given column, although separated. The fact that the full number of columns may yet be traced in dissociated plates quite near the dorsal terminus is brought out by the oblique line *X-Y* in plate 3, figure 13, which bisects the separated plates of the 8 perpendicular columns existent in this interambulacrum, and this fact is clearly brought out by the lines *X*, *Y*, *Z* in the diagram on page 164. This change to the rhombic form near the dorsal area is also shown by plate 5, figures 20, 21, plate 6, figure 31, and plate 7, figure 36.

Proof that the crowding out of columns is due to the narrowness of the area can only be obtained by getting young material, which several efforts failed to procure. Still, it is possible that in quite young stages, where the number of columns is smaller, all might continue to the dorsal termination without interruption, because the area would be relatively less crowded with fewer columns. The crowding out is distinctly not a dying out of columns, for when columns die out or cease to be continued to the dorsal area it is commonly the middle or last added column which drops out first in the cases observed, as shown in the dropping out of column 11 in the dorsal area of *Melonites giganteus* (plate 5, figure 21). The dying out of columns is a change from the progressive addition or maintenance of columns, and, in so far as it goes, may be regarded as a retrogressive feature. This is not a common feature, as observations show. In *Oligoporus missouriensis* (plate 9, figure 50) a sixth column of plates exists for a brief period, and in *Lepidesthes wortheni* (plate 9, figure 53) four columns of interambulacral plates are found ventrally, but one soon drops out.

These are the only cases observed of a reduction in the number of columns passing dorsally in any Paleozoic echini.*

VARIATIONS IN THE INTERAMBULACRUM.

Having described an ideal normal type of plate arrangement of the interambulacrum, it is desired to call attention to one of the most irregular specimens of *Melonites multiporus* seen. The specimen is in the collections of the Wagner Free Institute of Philadelphia, accession number 3226. It is in a large slab with several other individuals. The specimen (plate 3, figure 14) has eight columns in the interambulacrum. It thus gives an added column of plates as compared with that shown in plate 3, figure 12. Part of the plates of the area are hidden in the matrix, but those visible show the essential features for a comparison. At the ventral end, as far as seen, there are four columns of plates (plate 3, figure 14), but a fifth column is soon introduced by the pentagon number 5. This column at its point of origin has two columns on either side. The sixth column is introduced by pentagon 6. It has a heptagon on the left, which is a member of column 5, and has three columns on the left and two on the right at its point of origin, as in plate 3, figure 12. The seventh column is introduced by pentagon 7, having a heptagon on the left, which is a member of column 5 instead of column 6, as in plate 3, figure 12. Column 7 has the usual number of columns on either side. Column 8 is peculiar in that it originates with a hexagonal plate 8 instead of with a pentagon, as in the cases previously mentioned and as seen in column 8 of the cases tabulated on pages 165 to 170. This column at its point of origin has four columns on the left and three on the right, the theoretically correct position for an even-numbered column (compare with plate 5, figure 20, and plate 3, figure 12). Hexagon 8 has an octagonal plate, *O*, on the left, which is a member of column 7. The octagonal form of this plate is caused by the reëntrant angle made by the hexagonal form of plate 8. It is seen in the diagram (plate 3, figure 15) that a change to the pentagonal form of plate 8, together with a slight shifting of associated plates, would make both these plates of the usual form. The specimen is of interest as showing the development of the eighth column in its correct position by our law of alternation; also as showing that the first formed plate of a newly introduced column is not always a pentagonal plate;

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* In the E. M. Museum at Princeton, New Jersey, there are three specimens (catalogue numbers 1464, 1466, 1466*a*) which show the jaws in place. These consist of 10 dental pyramids lying opposite the interambulacral areas. When complete they meet orally in acute terminal angles. In two specimens (1464 and 1466) part of the ambulacral and a few interambulacral plates of the peristome are preserved. These plates are more or less irregular, and the ambulacral plates have two pores. The specimens were seen too late to include them in this paper further than by this note.

this and a few other cases which are figured* or described, being however, the only exceptions seen to the rule of terminal pentagonal plates (above number 3, plate 2, figure 2) seen in either *Melonites* or *Oligoporus*, which is somewhat remarkable, as in these two genera terminal plates are figured or tabulated in this paper in more than 260 columns, all but six of which were pentagonal (or hexagonal, when initial plates of column 3), and these exceptions were in all cases due to peculiar local conditions, as described.

Another feature shown by this specimen is the fact that heptagonal plates, which lie next to terminal pentagons, are not necessarily members of the immediately preceding column. Other cases of this variation from the typical position of heptagonal plates, which are not infrequent, are seen in the tables on pages 165–170. From lateral thrusts and pressure a new column is introduced the initial plate normally takes on a when pentagonal form and an adjacent plate takes on a heptagonal form, this being a mechanical compensation for the missing side of the pentagon in an area where plates are either hexagonal or the equivalent.

A peculiar case of irregular arrangement of plates is that shown in the ventral area of *Melonites multiporus*, plate 3, figure 16.† The ventral plates 1 and 2 show on their lower border a reëntrant angle for the missing initial interambulacral plate (compare with plate 3, figure 10), as discussed above; the third column originates in a pentagonal plate, number 3, this being the only case observed in which this plate was not hexagonal (compare plate 2, figure 2); the second plate, *H*, in the third column is heptagonal and very irregular in form; the initial plate of the fourth column, number 4, originates in the fourth instead of the third row, its characteristic position, and is heptagonal, its ventral termination making a reëntrant angle in plate *H* and being truncated dorsally by pentagon 5; the other plates of the area are of the usual form. Only one other case, plate 3, figure 12, has been seen in which plate 4 did not originate in immediate contact with initial plate 3. It has been stated that the normal form of median plates of the interambulacrum is hexagonal, and it is worth noting that this case makes only a modification of the rule. The sum total of plates 3, *H*, 4, and 5 gives 24 sides, which divided by four gives an average of six sides to each plate.

In a specimen in the Museum of Comparative Zoölogy (catalogue number 3021) two peculiar variations from the normal exist. In this specimen (plate 2, figure 7) the initial plate 6 of the sixth column is tetragonal, a rare variation; also, the heptagonal plate *H*, associated with the terminal pentagon 8 of column 8, occurs not adjacent to the pentagon

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* Plate 2, figures 6 and 7; plate 3, figure 16; plate 5, figure 21.

† The specimen is in Yale University Museum, diamond number 157, specimen B.

but in the fifth instead of the seventh column, as usual. This heptagon, it is to be noted, is in the correct horizontal row, although in an unusual vertical column. Two or three similar cases of unusual position of heptagonal plates have been observed in *Melonites multiporus* and *Melonites giganteus*, Jackson (see area *I* in tabulation of the latter species).

In the E. M. Museum at Princeton, New Jersey, there is a specimen of *Melonites multiporus* (catalogue number 1462) which has nine columns of plates. The initial plate of column 5 is tetragonal with two adjacent heptagonal plates, as in initial plate 6, of plate 2, figure 7. Another peculiarity is the fact that column 7 at its point of origin has four columns on the left and two on the right instead of being median in position. An adjacent interambulacrum of the specimen is normal, not showing the mentioned local peculiarities.

A peculiar terminal plate of column 4 is shown in plate 3, figure 10. In this specimen the initial plate of its column is tetragonal in form, and this is almost the only case of the kind seen, except that shown in plate 2, figure 7', and plate 2, figure 6. This plate impinges on the dorsal border of initial plate 3 in the usual manner (compare with plate 2, figure 2). It is shown that newly introduced plates near the dorsal area are rhombic in form, and it would seem that from the quick introduction of the second plate 4′ in this column the initial tetragonal plate 4 had been checked in its development so as never to assume the typical form.

While in the body of the interambulacrum only terminal ventral plates of newly added columns are pentagonal, a few exceptions have been observed in which other plates have a pentagonal form. Such a case is seen in plate 3, figure 17, where, besides the initial pentagon of column 8 there are two accessory pentagons developed, one, *P*, on the left of pentagon 8 and one, *P′*, on the dorsal border of the same. We see nothing to account for this peculiarity, which is exceedingly rare, except chance variation. In this case it would seem that either pentagon 8 or *P* might be selected as the initial pentagon of column 8, but the left-hand pentagon is evidently a member of column 7; also selecting the right-hand pentagon for the terminal brings column 8 in its correct theoretical position, with four columns on the left and three on the right.

Melonites multiporus is described as having seven or eight columns of plates in the interambulacrum. This is the rule; but in the large series of specimens examined many exceptions have been found in which nine columns existed in the interambulacrum. Thirteen of such areas are tabulated in the tables on pages 165 to 170. One of the best examples seen is that shown in plate 5, figure 20. In the right-hand interambulacrum of this specimen, columns 5, 6, 7 and 8 originate in pentagonal plates, as numbered, with heptagonal plates on their left or right, in exact accordance with the law as worked out in this paper.* The ninth column originates in pentagon 9, with a heptagonal plate on its right ventral side, and with four columns of plates on either side, thus taking its correct theoretical position. The same statement holds good for the introduction of the eighth and ninth columns in the left adjoining interambulacrum of the same specimen, as shown in the figure. This departure from the rule of having only seven or eight columns is a variation which might be expected in a type of echinoderms which has already such a multiplication of parts. It is a variation in the direct line of progressive ascent in the group to which it belongs, eleven columns being characteristic of *Melonites giganteus* (plate 5, figure 21), the next higher species of the genus.

The introduction of the ninth column is shown in plate 2, figure 6, a specimen which is also included in the table on page 169. In this specimen (number 3017) the initial plate of the ninth column is rhombic. It has only built a few plates, having originated shortly before the addition of new plates ceased in the life of the individual. A heptagonal plate lies on its right lower side, as usual.

While in some cases nine columns of interambulacral plates develop in several interambulacral areas of a specimen, it is not infrequent that only one or two areas acquire nine columns, while other areas of the same specimen have no more than eight. This fact is brought out in the tabulations of areas which are considered in succeeding pages.

IMBRICATION OF PLATES.

Having described the typical arrangement of ambulacral and interambulacral plates in *Melonites multiporus*, it is desired to leave temporarily the consideration of interambulacral areas and take up the matter of imbrication and the genital and ocular plates as described in this and the succeeding sections.

Imbrication of plates is quite a common feature in Paleozoic echinoids, being most strongly marked in *Lepidocentrus*, *Lepidechinus* and allies. In the Melonitidæ † the imbrication is very slight. The ambulacral plates have practically perpendicular sides, both laterally and dorso-ventrally (plate 2, figure 5); what inclination occurs may be accounted for by the mechanical necessity for inclined edges in thick plates which form an arcuate test.

In the interambulacrum the adambulacral plates imbricate under the adjacent ambulacrals (plate 2, figure 5) and not over them, as in *Lepidocentrus* and *Lepidechinus*. The median columns of plates of the inter-

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* Excepting that the heptagon next pentagon 5 should be on the right.

† Excluding the genus *Lepidesthes* and allies, which are placed in a family by themselves, the *Lepidesthidæ*, Jackson. (See systematic table in the succeeding paper under "Conclusions.")

ambulacrum can not be said to show imbrication. They are very thick in the species *Melonites multiporus* (plate 2, figure 5), and thicker still in *Melonites giganteus*, Jackson, as shown in the broken portion of area I (plate 4, figure 19). The several sides of the plates diverge upward and outward as a mechanical necessity to fill space in a curved test. In species where the test is thin, as in *Oligoporus coreyi*, M. and W., the wedge-like form of the plates is less apparent than in species where the plates are thicker as described.

The details of imbrication or want of it as described in *Melonites multiporus* have been also observed in *Oligoporus danæ* and *Rhoechinus elegans*. Therefore this type of mutual plate contact may be considered as characteristic of the famlly.

GENITAL AND OCULAR PLATES AND DISCUSSION OF ORIENTATION.

In the Johns Hopkins specimen of *Melonites multiporus* (plate 3, figure 13) the genital plates are seen in all five areas. In these plates there are three, or four pores in each plate. The same condition occurs in a specimen in the Museum of Comparative Zoölogy (catalogue number 3077), and in a specimen in the Boston Society of Natural History (catalogue number 11569), in both of which five genital plates are preserved intact. In no case have five pores or less than three pores been observed in a genital plate, though altogether quite a large number of plates have been examined. The same condition of pores has been observed in *Oligoporus missouriensis*, Jackson, as described in the succeeding paper.

Messrs Meek and Worthen (30) have figured the genital and ocular plates of *Melonites multiporus*, and in their figure each of the genital plates has four or five pores. We would not question the accuracy of their figure, for all the work of these authors on Paleozoic echini is of the most painstaking and accurate kind; but it is felt that this large number of pores is not to be considered the normal or average condition, being rather an unusual increase. Mr C. R. Keyes (23) has recently published a figure of *Melonites multiporus*, in which the genital plates have three pores in two cases and four in two others. The fifth plate has a single large pore, but has a number of minute ones, and is described as a madreporic plate. We have not seen any genital plate with less than three pores and have never seen evidence of a madreporic character in any of the plates. Some one of the plates, from analogy, one would suppose must be madreporic in nature, and it is important that Keyes has shown it may be found, although specimens showing it must be very rare. It seems possible that there is in his figure some error about the single large pore; but if it is correct, then a reduction as well as an increase from the normal number must be allowed for.

The ocular plates of *Melonites multiporus* have never been figured as perforated by pores, although Meek and Worthen (30) suggested that they may perhaps sometimes show pores. We have had the opportunity to examine a good many ocular plates in *Melonites multiporus*, and in no case were they perforated. The same observation is true of *Oligoporus missouriensis*, Jackson.* It seems best to give up finally the idea of pores in the oculars of adult *Melonites,* unless some are actually observed. Pores in ocular plates are so constant a feature in echinoids (two are figured in *Palæechinus* by Bailey (5)) that *Melonites* and *Oligoporus* must be considered as exceptional in this feature, and quite likely they would be found in the young, if such material could be obtained.

In the figures (2, 18, 20) and tables (pages 165–170) of *Melonites multiporus* the several areas are oriented, the interambulacra and ambulacra being designated by letters from *A* to *J*, inclusive. As madreporic plates have not been seen, any interambulacral area is selected as a starting point and succeeding areas are counted from left to right, revolving like the hands of a watch, when looking down on the echinus from the dorsal side. The orientation is necessarily reversed when the echinus is viewed from the ventral side (plate 2, figure 2). It would be interesting if means of differentiating areas could be established; but at present it seems impossible, for the areas, as far as known, present no radial specializations. If a definite method of orientation could be established from genital plates, it is feared that this would not aid one in orienting areas in specimens which were imperfect dorsally. Perhaps the orientation adopted in these papers is as convenient as any that could be practically applied.

Tabulations of Plate Arrangement in the interambulacral and ambulacral Areas.

In order to give a description in brief form of a greater number of interambulacral and ambulacral areas in *Melonites multiporus* than could be figured, the accompanying tables are introduced. Besides giving other additional cases, these tables represent the arrangement in cases where it would be impossible to figure them adequately, as in areas on the opposite sides of the same specimen.

In the tables the characters to be compared are arranged in perpendicular lines. The interambulacral areas, indicated by letters *A*, *C*, *E*, *G* and *I*, are all considered as successive areas, as seen looking down on the test from the dorsal side and revolving from left to right like the hands of a watch. This is the same notation that has been pursued in the plates, as plate 4, figures 18 and 19, plate 5, figure 20. The first column

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* See succeeding paper, plate 9, figure 52.

in a table gives the total number of columns of plates in the area. Unless the area is nearly or quite complete dorsally this number is omitted, for if the area is incomplete any number stated might be too low. In the second column the number of the column is given; in the third the form of the plate in which the column terminates ventrally, indicated by *P* if pentagonal and by *X* if hexagonal, or if otherwise by reference to foot-notes. In the fourth column is given the number of the horizontal row counting from the oral end in which the given column of plates originates. There are two plates only at the oral end of an adult, and these are called row number 1, and succeeding rows are counted from that point upward (compare with plate 2, figure 2). Obviously in most cases the oral termination is incomplete. In such cases the position of the first introduced column is assumed to be in the average position; but the affixed number is then indicated by an asterisk, excepting when only one row is wanting and the interambulacrum begins with the initial plate of column 3. The advantage of this is to give the relative position above the first observed column of its later added fellows. The application of this notation is seen in the table of specimen number 3010. The fifth and sixth columns indicate the number of columns on the left and right of a column at its ventral termination, or when first introduced. The seventh column gives the position of heptagonal plates whether on the left or right of terminal pentagons. Any special exceptions are indicated in foot-notes. For the sake of an easy comparison of the several columns and to show individual variation, the characters which conform to the ideal law of growth are printed in Roman characters; those which are variations from the ideal or normal are printed in *italics*, so as to be readily picked out. It may be stated that the specimens were not selected otherwise than as being sufficiently perfect to show satisfactorily the features of plate arrangement. More tabulations might have been included, but they were omitted for the sake of brevity. It will therefore, we think, be conceded that the variations from the normal ideal type are relatively few. A comparison of the arrangement indicated in these tables should be made with the similar table of *Melonites giganteus* in the succeeding paper and with the figures of the several genera and species figured in the plates; also with the ideal reconstruction (see figure 1, page 164).

REMARKS ON THE TABLES OF PLATE ARRANGEMENT.

The first case (page 165) is specimen 3016 * in the Museum of Comparative Zoölogy. This specimen is remarkable in that it has the 10 ambulacral and interambulacral areas preserved almost in their original com-

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* This specimen was purchased of Ward, of Rochester, for the Student Paleontological Collection, but since its value was ascertained, it has been transferred to the Museum.

pleteness. It is noteworthy that at first sight it is a specimen of indifferent quality, being considerably worn and compressed. By critical study all the areas were made out, as indicated in the table. The first row of interambulacral plates is absent, but the second exists in each area. The ambulacra have 4 columns of plates at the ventral termination in all 5 areas, the characteristic condition at this portion of the test. Three interambulacra, *E*, *G* and *H*, have 9 columns of plates, but the other two areas, *A* and *E*, have only 8. They might, however, have shown a ninth column added if preserved to the dorsal area where they are wanting. The initial plates of column three in the 5 areas are hexagonal as usual. The other 25 terminal plates of columns in the specimen have the regulation pentagonal form. Columns 3 and 4 originate in the second and third row respectively in all areas. Initial plate 4 truncates the dorsal border of initial plate 3 as usual. Column 5 originates in the fifth or sixth row, column 6 in the ninth or tenth row, column 7 in the twelfth or thirteenth row, and column 8 in the sixteenth or seventeenth row. The ninth column originates in the one area where counted in the twenty-third row. The ninth column in area *I* originates one column too far to the right, but the other 16 odd-numbered columns originate in a median position, with an equal number of columns on either side. Of the 13 even-numbered columns, 11 originate with one more column on the left than on the right; the other two originate with one more column on the right than on the left. Of the 18 heptagonal plates adjoining terminal pentagons, 13 occupy the correct theoretical position. Thus this specimen is very nearly normal as well as very perfect, showing little departure from the ideal type of plate arrangement, excepting in the unusual position of the ninth column in area *I*.

The next specimen tabulated (page 166) is also important as showing the arrangement in 5 interambulacra for comparison. This specimen, number 3010, is in the Museum of Comparative Zoölogy. Each ambulacral area has four columns of plates ventrally. All the areas are wanting in the dorsal portion, as that is firmly bedded in the rock. One interambulacral area, *I*, shows 8 columns of plates; the other 4 areas show only 7. It is possible, even probable, that an eighth would have been added to some of them if the dorsal portion were visible. Initial plates of column 3 are shown in areas *C*, *E* and *I*. All are hexagonal, having their dorsal borders truncated by initial plate 4 of column 4. All the other 20 columns tabulated originate in pentagonal plates. The same numbered column originates in nearly or quite the same row in each of the 5 areas. A close comparison of the row in which columns originate is requested in this table and the preceding one. This will give one a good idea of the definite uniformity of growth maintained throughout the corona in two very perfectly preserved and quite average specimens in all details. The odd-numbered columns are all median at their point of origin. Six even-numbered columns are out of place, originating one row too far to the left; also 6 heptagonal plates occupy the incorrect position. Otherwise the specimen conforms entirely to the ideal method of arrangement as here formulated.

The specimen (number 2991) next considered (page 167) is in the Museum of Comparative Zoölogy. It has 4 columns of ambulacral plates ventrally in the 4 areas shown; also there are 3 interambulacral areas which are preserved from the second row of plates nearly to the dorsal termination of the areas. The initial plates of 14 columns shown are pentagonal. The initial plate of column 3 in area *C* is hexagonal, but in areas *A* and *E* the ventral border of the initial plate 3 is not shown; therefore, though doubtless hexagonal, the form is not given. The several columns in each area originate in about the usual row as compared with each other and with other specimens. The 9 odd-numbered columns are all median in position at the point of origin. Four even-numbered columns are out of place, being one column too far to the left; also 5 heptagons are in the incorrect position, by rule; otherwise the plate arrangement is entirely normal throughout.

Specimen number 3021 (page 167) in the Museum of Comparative Zoölogy has 9 columns in both areas shown. Area *A* is complete dorsally; one column, the eighth, is one column too far to the left at its point of origin, but otherwise this area conforms to the ideal in all details of its plate arrangement. Area *C*, however, is one of the most irregular areas met with in any specimen. It is figured in plate 2, figure 7. The ninth column of this area has 5 columns on the left and 3 on the right at its point of origin. This is a very unusual variation, for odd columns are almost universally median in position. A few similar cases will be noticed in other tables. The sixth column in the same area, *C*, terminates ventrally in a tetragonal plate, which is a very rare variation; only four other similar cases have been met with in any Palæechinoid. One heptagon, that next pentagon 9, is out of place. The heptagon which should come next to pentagon 8 lies in the correct horizontal row, but exists as a member of column 5 instead of column 7. This curious variation of position of the heptagon has been observed in only one other case in *Melonites multiporus*. It has been observed, however, in *Melonites giganteus* (see the table of that species, area *I*, column 11). Interambulacrum *A*, it is interesting to note, is almost entirely normal throughout, only one even-numbered column being out of place. The columns of plates are introduced at the same row in each area. Comparing the two areas of this specimen, it is seen that the irregularity of one area is not repeated in the other area, and this remark applies to studies of variations in the interambulacrum generally. In the development of the several areas of any given specimen of *Melonites* we find that the several columns are added at the same or nearly the same horizontal plane (as indicated by the numbers in the fourth column of the tables), but irregularities, such as seen in the position of heptagons or point of origin of columns, are not repeated in succeeding areas unless by chance, for on the principle of chances similar variations in two or more areas would occasionally occur.*

The specimen of *Melonites multiporus* number 3023 (page 168) in area *A* has the same irregular position of the ninth column as specimen 3021, having 5 columns on the left and 3 on the right at its origin; also column 8 and two heptagons are out of place, otherwise the specimen is normal, conforming to the ideal arrangement throughout both areas.

The next tabulation is of a specimen of *Melonites multiporus* given to Yale University Museum (page 168) as a slight return for many favors received. In the two interambulacral areas shown there are 9 columns of plates. All initial plates of columns are pentagons. The arrangement of details is entirely normal except that two heptagons, next pentagons 5 and 7, are on the wrong side, and one of these heptagons is too far to the left, as noted. Two ambulacra show 4 columns of plates at the ventral termination. A specimen, number 3007 (page 168), in the Museum of Comparative Zoölogy shows two ambulacral and two interambulacral areas. Interambulacrum *C* has two even-numbered columns, one row too far to the left and one heptagon out of place; otherwise the arrangement of this specimen is entirely normal in its details.

The next specimen tabulated is owned by Mr T. A. Jaggar (page 169). Interambulacrum *A* has all the even-numbered columns left-handed or with one more column on the right than on the left at the point of origin; also and perhaps as a correlated feature all the heptagons adjacent to pentagons are on the wrong side in the several cases. Such uniform variation from the normal has not been seen in any other specimen of an interambulacral area. The next interambulacrum, *C*, of the same specimen is perfectly normal throughout, except that two heptagons occupy an incorrect position. Ambulacrum *B* has four columns of plates at the base, as usual.

Specimen number 3017 (page 169) has 9 columns of plates in areas *A* and *I* and 8 columns in the other 3 areas. The arrangement is normal as far as visible, except that one heptagon is out of place and column 9 in

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* For this matter of variation it is desirable to study the figures and tables of *Melonites* with the idea of radial variation especially in mind. The figures of *Palæechinus* (plate 7, figure 36) and *Archæocidaris* (plate 8, figures 43–45) may also profitably be considered under this study of radial variation.

area *I* terminates in a ventral plate, which is tetragonal or rhombic in form. This plate, which is shown in plate 2, figure 6, is quite near the dorsal termination of the area.

Specimen number 3019 (page 169) shows only one area, which has 9 columns of plates. The ninth originates quite close to the dorsal termination of the area, as in the above case, and its terminal plate is rhombic in form. The arrangement of the areas is entirely normal, excepting the tetragonal plate and one heptagon, which is out of place.

Specimen number 3020 (page 169) is normal throughout, except that one column, the eighth, originated one column too far to the left; also one heptagonal plate is out of place.

Specimen number 3022 is entirely ideal in its arrangement throughout, unusually normal in fact, for some variation is commonly met with.

Specimen number 2992 (page 170) is peculiar in having one odd-numbered column, the seventh in area *C*, one column too far to the right; also two even columns in area *A* are too far to the left, and three heptagons are out of place. One area, *C*, has but 7 columns of plates, whereas the other has 8, both areas being complete dorsally.

Specimen 2999 (page 170) has 9 columns of plates and is normal throughout in its plate arrangement.

Specimen 3004 (page 170) has two columns and one heptagon out of place. The irregular position of column 7 is noteworthy, because it is unusual for odd columns to be otherwise than median in position.

Specimen number 3006 (page 170) is entirely normal throughout.

Having stated the law of growth in the interambulacrum of *Melonites multiporus*, and having figured and tabulated the arrangement in many specimens, it is desirable to foot up the results of the observations and see how closely actual observations come to the assumed law of introduction and arrangement of plates. In this summary are included all the figures given of *Melonites multiporus* in the accompanying plates; also the tabulations of the same species. In a few cases the same area is included in a figure and also in a table, when of course but one count is made. For most of the details considered we have also included the results obtained from the tabulation of *Melonites giganteus*, Jackson, as described in the succeeding paper. From the context it will be made plain when both species or only one species are included.

In considering this summary constant comparisons with the figures of *Melonites* should be made, especially the ideal diagram on page 164. Comparison is also requested with the plate arrangement illustrated in the succeeding paper in the genera *Oligoporus*, *Palæechinus*, *Archæocidaris*, *Lepidocidaris* and *Lepidechinus*, where the same method of growth prevails in its principles, but varies somewhat from generic differences of structure.

Summing up, we find that in *Melonites multiporus* 35 interambulacral areas are figured or tabulated which are nearly or quite entire dorsally. Of these 2 have 7 columns of plates, 18 have 8 columns, and 15 have 9 columns. Therefore it may be stated that 7 columns is an unusually small number of columns for this species, it usually possessing either 8 or 9, with about even chances for either number, but slightly preponderating in favor of 8. Nine columns of plates have never been described as existent in this species, which is somewhat strange, as this number is evidently so frequent.

The introduction of new columns (succeeding columns numbers 1 and 2) is shown in 248 cases in *Melonites multiporus* and *giganteus*. Of these the initial plates of the columns are pentagonal in 220 instances, in every case of which an apex of the pentagon is directed ventrally and a side of the pentagon is directed dorsally. Twenty-two of the terminal plates are initial hexagons of column number 3, which is the normal form in this instance. Only in 6 cases out of the whole number 248 are the initial plates of columns other than the regulation form; that is, the form of the initial plates of columns is correct by rule in 97+ per cent of the cases.

In the matter of the position of introduction of columns of *Melonites multiporus* as expressed by the number of rows from the base in which the column originated, there is for the most part great uniformity. Columns 1 and 2 always are represented by the two plates found at the ventral termination,* as observed in 21 cases (page 143).† The third column originated in the second row, as shown in 26 cases. The fourth column originated in the third row, as observed in 27 cases; in one specimen (plate 3, figure 16) this column originated in the fourth row and in one (plate 3, figure 12) it originated considerably later; but these are the only exceptions that have been seen. The fifth column originates in the fifth row in 3 cases, in the sixth row in 17 cases, in the seventh row in 8 cases, and in the eighth row in 7 cases; therefore the fifth column in the great majority of cases originates in the sixth row. The sixth column in 10 cases originates in the ninth row, in 18 cases in the tenth row, and in

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*That is, the ventral termination as normally existing in an adult. In this summing up of areas the initial first formed plate 1′ (plate 3, figure 10) is not considered. It is a feature properly belonging to an earlier period of growth and is resorbed by the encroachment of the peristome. We are now considering the adult, and therefore consider the ventral border as it exists in that period of growth.

†Excepting this statement in regard to the first two columns, all the observations cited are those figured in plates or shown in detail in the tables. Of course many other observations were made, but we limit the remarks to the published observations.

7 cases in the eleventh row; the sixth column, therefore, in the majority of cases originates in the tenth row. The seventh column in 4 cases originates in the twelfth row, in 15 cases in the thirteenth row, in 11 cases in the fourteenth row, in 3 cases in the fifteenth row, and in one case in the seventeenth row; the seventh column, therefore, originates in the great majority of cases in either the thirteenth or fourteenth row, but occasionally lower or higher. The eighth column originates in the sixteenth row in 5 cases, in the seventeenth row in 7 cases, in the eighteenth row in 5 cases, in the nineteenth row in 5 cases, in the twentieth row in 3 cases, and in the twenty-second row in one case; there is considerable variation, therefore, in the period of introduction of the eighth column without special preponderance in favor of any one row; the sixteenth to the nineteenth row may be taken as the average swing in rate of appearance of this column. The ninth column has a similar wide swing in its period of introduction; it originates in the twentieth row in 3 cases, in the twenty-first row in three cases, in the twenty-second row in 2 cases, in the twenty-third row in 3 cases, and in the twenty-fifth row in one case; this ninth and last column added, therefore, makes its appearance in a majority of cases in the twentieth to the twenty-third row.

The interesting result of this tabulation of periods of appearance of columns is to show with what regularity the several columns were introduced in the development of the animal, all appearing within the close limits of a perfectly definite period in growth. As might be expected, the columns added first, from 1 to 4, inclusive, are the most constant in their rate of appearance, later added columns being more variable, yet a pretty close adherence to the abstract law of specific periodicity is maintained in all the columns as added. Comparing this rate of introduction of columns with that of *Melonites giganteus*, we find most suggestive and interesting conclusions, as discussed under the consideration of that species in the succeeding paper.

Turning to the results obtained in other columns of the tables, we would again include *Melonites multiporus* and *Melonites giganteus* in one consideration of the details. Out of a total of 138 odd-numbered columns introduced, all but 6, or 95+ per cent, originate in the middle, with an equal number of columns on either side. In these 6 exceptions the column had one more column on the left than on the right, or was right-handed.

In the cases of 113 even-numbered columns 82 originated with one more column on the left than on the right, and 31 originated with one more column on the right than on the left; that is, 72+ per cent were in the theoretically correct position, or left-handed. In no case of column arrangement in either odd- or even-numbered columns was the newly introduced column more than one column out of place to the left or right. The same remark applies to all the studies of Palæechinoids as presented in the succeeding paper, excepting the case of *Melonites septenarius* (plate 9, figure 49), as there described.

The heptagonal plate adjoining the terminal pentagon should by rule lie to the right of the pentagon terminating odd-numbered columns, and to the left of the pentagon terminating even-numbered columns. The position of the heptagonal plate is shown in 171 cases, and of those it occupies the correct position in 122 instances and the incorrect position in 49 instances. In other words, it occupies the correct position in 71 per cent of the cases.

From this close adherence to the theoretical method of growth we are justified in giving the annexed diagram as representing the correct method of plate arrangement in *Melonites* and the average number and relations of plates existent in *Melonites multiporus* in the adult condition. In the figure all the plates are put in according to rule as deduced from the compilation of numerous critical observations. The supposed initial plate 1′ is included in the figure so as to indicate all the plates it had at any period of growth, but it should be distinctly understood that this plate is typically resorbed in the adult condition. Nine columns of plates might have been introduced in this figure, but it is intended to represent the ideal, and 8 columns are somewhat more frequent in perfect specimens than 9. The lines *X*, *Y*, *Z* are drawn so as to bisect 8 columns of plates. They therefore indicate by their progressively narrowing angle, the stringing-out arrangement of plates in the dorsal area as described on page 150. (Compare with the line *X-Y* in plate 3, figure 13.)

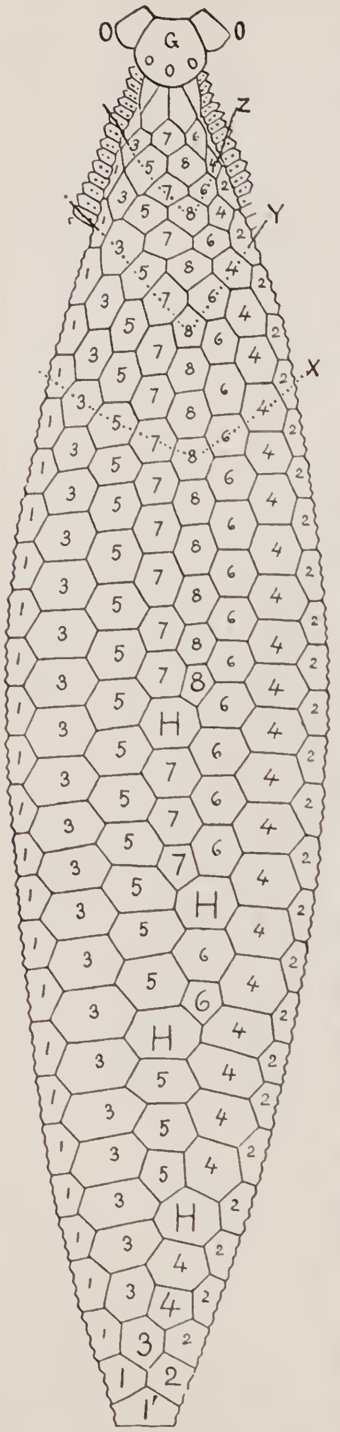

FIGURE 1.—*Ideal Arrangement of interambulacral Plates in Melonites multiporus.*

TABLES OF PLATE ARRANGEMENT.

Melonites multiporus. Museum of Comparative Zoölogy catalogue number 3016.	Number of columns in the area.	Column number.	Terminates ventrally.	Originates in row from base.	Columns on left of, at origin.	Columns on right of, at origin.	Heptagon on left or right of terminal pentagon.
Interambulacrum A *	8	8	P	16	4	3	Left.
		7	P	12	3	3	*Left.*
		6	P	9	*2*	*3*	Indistinct.
		5	P	5	2	2	Indistinct.
		4	P	3	2	1	Truncates initial plate 3.
		3	X	2	1	1	....
	First row of plates wanting.						
Ambulacrum B	Four columns of plates at base.						
Interambulacrum C *	8	8	P	17	4	3	Left.
		7	P	13	3	3	Right.
		6	P	9	3	2	Left.
		5	P	5	2	2	Right.
		4	P	3	2	1	Truncates initial plate 3.
		3	X	2	1	1	....
	First row of plates wanting.						
Ambulacrum D	Four columns of plates at base.						
Interambulacrum E *	9	9	P	....	4	4	Right.
		8	‡	....	....	....	....
		7	P	13	3	3	Right.
		6	P	10	3	2	Left.
		5	P	6	2	2	Right.
		4	P	3	2	1	Truncates initial plate 3.
		3	X	2	1	1	....
	First row of plates wanting.						
Ambulacrum F	Four columns of plates at base.						
Interambulacrum G †	9	9	P	23	4	4	*Left.*
		8	P	16	4	3	*Right.*
		7	‡	....	....	....	....
		6	P	9	3	2	Left.
		5	P	6	2	2	*Left.*
		4	P	3	2	1	Truncates initial plate 3.
		3	X	2	1	1	....
	First row of plates wanting.						
Ambulacrum H	Four columns of plates at base.						
Interambulacrum I *	9	9	P	....	*5*	*3*	*Left.*
		8	‡	....	....	....	....
		7	P	12	3	3	Right (?) §
		6	P	9	3	2	Left.
		5	P	6	2	2	Right.
		4	P	3	*1*	*2*	Truncates initial plate 3.
		3	X	2	1	1	....
	First row of plates wanting.						
Ambulacrum J	Four columns of plates at base.						

* Interambulacrum wanting at the dorsal portion of the area.

† Interambulacrum complete at the dorsal portion of the area.

‡ Wanting at this portion of the area.

§ Plate on the left of pentagon 7 is hexagonal; on the right the plates are broken away so that angles cannot be determined.

Melonites multiporus. Museum of Comparative Zoölogy catalogue number 3010.	Number of columns in the area.	Column number.	Terminates ventrally.	Originates in row from base.	Columns on left of, at origin.	Columns on right of, at origin.	Heptagon on left or right of terminal pentagon.
Interambulacrum A*	....	7	P	14	3	3	*Left.*
		6	P	10	*2*	*3*	*Right.*
		5	P	7 ?	2	2	Right.
	Indistinct at lower part.						
Ambulacrum B	Four columns of plates at base.						
Interambulacrum C*	....	7	P	13	3	3	Right.
		6	P	10	3	2	Left.
		5	P	7	2	2	Right.
		4	P	3	*1*	*2*	Truncates initial plate 3.
		3	X	2	1	1	....
	First row of plates hidden.						
Ambulacrum D	Four columns of plates at base.						
Interambulacrum E*	....	7	P	13	3	3	*Left.*
		6	P	10	*2*	*3*	*Right.*
		5	P	7	2	2	Right.
		4	P	3	2	1	Truncates initial plate 3.
		3	X	2	1	1	....
	First row of plates wanting.						
Ambulacrum F	Four columns of plates at base.						
Interambulacrum G*	....	7	P	14	3	3	Right.
		6	P	10	3	2	Left.
		5	P	7	2	2	Right.
		4	P	3 ?	2	1	Truncates initial plate 3.
	First two rows of plates obscure.						
Ambulacrum H	Four columns of plates at base.						
Interambulacrum I*	8	8	P	20	*3*	*4*	(?)
		7	P	15	3	3	*Left.*
		6	P	11	*2*	*3*	*Right.*
		5	P	8	2	2	Right.
		4	P	3	*1*	*2*	Truncates initial plate 3.
		3	X	2	1	1	....
	First row of plates obscure.						
Ambulacrum J	Four columns of plates at base.						

* Interambulacrum invisible in the dorsal portion of the area, being more or less deeply buried in the rock.

Melonites multiporus. Museum of Comparative Zoölogy catalogue number 2991.	Number of columns in the area.	Column number.	Terminates ventrally.	Originates in row from base.	Columns on left of, at origin.	Columns on right of, at origin.	Heptagon on left or right of terminal pentagon.
Ambulacrum J	Four columns of plates at base.						
Interambulacrum A*	8	8	P	19	4	3	Left.
		7	P	15	3	3	Right.
		6	P	11	3	2	Left.
		5	P	7	2	2	Right.
		4	P	3	2	1	Truncates initial plate 3.
		3	‡	2	1	1	....
	First row of plates and ventral border of second row wanting.						
Ambulacrum B	Four columns of plates at base.						
Interambulacrum C*	8	8	P	18	4	3	*Right.*
		7	P	13	3	3	*Left.*
		6	P	9	*2*	*3*	*Right.*
		5	P	6	2	2	Right.
		4	P	3	*1*	*2*	Truncates initial plate 3.
		3	X	2	1	1	....
	First row of plates wanting.						
Ambulacrum D	Four columns of plates at base.						
Interambulacrum E*	....	7	P	13	3	3	Right.
		6	P	10	*2*	*3*	*Right.*
		5	P	6	2	2	*Left.*
		4	P	3	*1*	*2*	Truncates initial plate 3.
		3	‡	2	1	1	....
	First row of plates hidden or wanting.						
Ambulacrum F	Four columns of plates at base.						
Melonites multiporus. Museum of Comparative Zoölogy catalogue number 3021.							
Interambulacrum A†	9	9	P	21	4	4	Right.
		8	P	17	*3*	*4*	(?) Not visible.
		7	P	13	3	3	Right.
		6	P	9	3	2	Left.
		5	P	6	2	2	Right.
		4	P	3	2	1	Truncates initial plate 3.
		3	X	2	1	1	....
	Two plates in first row.						
Ambulacrum B	Four columns of plates at base.						
Interambulacrum C† (Figured on plate 2, figure 7)	9	9	P	21	*5*	*3*	*Left.*
		8	P	17	4	3	‖
		7	P	13	3	3	Right.
		6	§	9	3	2	Heptagon on left and right.
		5	P	6 ?	2	2	Right.
	First three rows of plates wanting.						

---

* Interambulacrum wanting at the dorsal portion of the area.

† Interambulacrum complete at the dorsal portion of the area.

‡ Ventral border of plate 3 invisible.

§ This plate is tetragonal in form (see plate 2, figure 7), and to compensate for the loss of two sides there are two heptagonal plates, one on either side of tetragon 6.

‖ No heptagonal plate next pentagon 8, but a heptagonal plate exists in the row below pentagon 8 and in column 5. (See plate 2, figure 7.)

Melonites multiporus. Museum of Comparative Zoölogy catalogue number 3023.	Number of columns in the area.	Column number.	Terminates ventrally.	Originates in row from base.	Columns on left of, at origin.	Columns on right of, at origin.	Heptagon on left or right of terminal pentagon.
Interambulacrum A*.........................	9	9	P	21	*5*	*3*	Right.
		8	P	17	4	3	*Right.*
		7	P	13	3	3	Right.
		6	P	9	3	2	Left.
		5	P	6	2	2	Right.
		4	P	3	2	1	....
	First two rows of plates wanting.						
Ambulacrum B..............................	Four columns of plates at base.						
Interambulacrum C†....................	....	8	P	18	*3*	*4*	*Right.*
		7	P	13	3	3	Right.
		6	P	10	3	2	Left.
		5	P	7	2	2	Right.
		4	P	3	2	1	....
	First two rows of plates wanting.						
Melonites multiporus. Yale University Museum diamond number 2290.							
Interambulacrum A*.....................	9	9	P	20	4	4	Right.
		8	P	16	4	3	Left.
		7	P	13	3	3	*Left.*‡
		6	....	....	....	....	Broken; indistinct.
		5	P	8	2	2	Right.
		4	P	3	2	1	....
		3	X	2	1	1	Truncates initial plate 3.
	First row of plates wanting.						
Ambulacrum B..............................	Four columns of plates at base.						
Interambulacrum C*.....................	9	9	P	22	4	4	Right.
		8	P	18	4	3	Left.
		7	P	14	3	3	Right.
		6	P	11	3	2	Left.
		5	P	8 ?	2	2	*Left.*
	First five rows of plates wanting.						
Ambulacrum D.............	Four columns of plates at base.						
Melonites multiporus. Museum of Comparative Zoölogy catalogue number 3007.							
Interambulacrum A†......................	....	7	P	14	3	3	Right.
		6	P	11	3	2	Left.
		5	P	8	2	2	Right.
		4	P	3	2	1	Truncates initial plate 3.
		3	X	2	1	1	....
	First row of plates wanting.						
Ambulacrum B..............................	Four columns of plates at base.						
Interambulacrum C†......................	8	8	P	19	*3*	*4*	Left.
		7	P	14	3	3	Right.
		6	P	11	*2*	*3*	*Right.*
		5	P	8	2	2	Right.
		4	P	3	2	1	Truncates initial plate 3.
	First two rows of plates wanting.						
Ambulacrum D.......................	Four columns of plates at base.						

* Interambulacrum complete at the dorsal portion of the area.

† Interambulacrum wanting at the dorsal portion of the area.

‡ But in second rather than adjacent column, as in heptagon next pentagon 8 of plate 2, figure 7.

Melonites multiporus. Specimen in possession of Mr T. A. Jaggar, Jr.	Number of columns in the area.	Column number.	Terminates ventrally.	Originates in row from base.	Columns on left of, at origin	Columns on right of, at origin.	Heptagon on left or right of terminal pentagon.
Interambulacrum A*	8	8	P	19	*3*	*4*	*Right.*
		7	P	14	3	3	*Left.*
		6	P	10	*2*	*3*	*Right.*
		5	P	6	2	2	*Left.*
		4	P	3	*1*	*2*	Truncates initial plate 3.
		3	X	2	1	1	....
	First row of plates wanting.						
Ambulacrum B	Four columns of plates at base.						
Interambulacrum C*	8	8	P	19	4	3	Left.
		7	P	14	3	3	*Left.*
		6	P	10	3	2	*Right.*
		5	P	6 ?	2	2	Right.
	First three rows of plates wanting.						
Melonites multiporus. Museum of Comparative Zoölogy catalogue number 3017.							
Interambulacrum A †	9	9	P	23	4	4	Right.
		8	P	17	*3*	*4*	*Right.*
		7	P	13 ?	3	3	Right.
	Wanting below this level.						
Interambulacrum C †	8	8	P	17	*3*	*4*	Left.
		7	P	13 ?	3	3	Right.
	Wanting below this level.						
Interambulacrum E †	8	‡	....	....	....	....	....
Interambulacrum G †	8	‡	....	....	....	....	....
Interambulacrum I †	9	‡	§	....	....	....	Heptagon on right and left.
Melonites multiporus. Museum of Comparative Zoölogy catalogue number 3019.							
Interambulacrum †	9	9	‖	25	4	4	Right.
		8	P	16	4	3	*Right.*
		7	P	12	3	3	Right.
		6	P	9	3	2	Left.
		5	P	6 ?	2	2	Right.
	First four rows of plates wanting.						
Melonites multiporus. Museum of Comparative Zoölogy catalogue number 3020.							
Interambulacrum †	9	9	P	23	4	4	*Left.*
		8	P	19	*3*	*4*	Left.
		7	P	15	3	3	Right.
		6	P	10	3	2	Left.
		5	P	6 ?	2	2	Right.
	First four rows of plates wanting.						

* Interambulacrum wanting at the dorsal portion of the area.

† Interambulacrum complete at the dorsal portion of the area.

‡ Plates preserved at the dorsal portion of the area only.

§ This terminal plate is rhombic in form. (See plate 2, figure 6.)

‖ This column originates close to the dorsal termination of the area. Its terminal plate is rhombic in outline like other plates in its vicinity.

Melonites multiporus. Museum of Comparative Zoölogy catalogue number 3022.	Number of columns in the area.	Column number.	Terminates ventrally.	Originates in row from base.	Columns on left of, at origin.	Columns on right of, at origin.	Heptagon on left or right of terminal pentagon.
Interambulacrum A *	8	8	P	18	4	3	Left.
		7	P	12	3	3	Right.
		6	P	9	3	2	Left.
		5	P	6 ?	2	2	Right.
	First four rows of plates wanting.						
Interambulacrum C *	8	8	P	18	4	3	Left.
		7	P	12 ?	3	3	Right.
	Wanting below this level.						
Melonites multiporus. Museum of Comparative Zoölogy catalogue number 2992.							
Interambulacrum A †	8	8	P	20	*3*	*4*	*Right.*
		7	P	14	3	3	Right.
		6	P	10 ?	*2*	*3*	*Right.*
	First seven rows of plates indistinct or wanting.						
Interambulacrum C †	7	7	P	14	*4*	*2*	*Left.*
		6	P	10	3	2	Left.
		5	P	6 ?	2	2	Right.
	First three rows of plates wanting.						
Melonites multiporus. Museum of Comparative Zoölogy catalogue number 2999.							
Interambulacrum †	9	9	P	22	4	4	Right.
		8	P	17	4	3	Left.
		7	P	13	3	3	Right.
		6	P	10 ?	3	2	Left.
	First six rows of plates wanting.						
Melonites multiporus. Museum of Comparative Zoölogy catalogue number 3004.							
Interambulacrum †	8	8	P	22	*3*	*4*	Left.
		7	P	14	*2*	*4*	Right.
		6	P	10	3	2	*Right.*
		5	P	6 ?	2	2	Not visible.
	First four rows of plates wanting.						
Melonites multiporus. Museum of Comparative Zoölogy catalogue number 3006.							
Interambulacrum †	8	8	P	18	4	3	Left.
		7	P	14	3	3	Right.
		6	P	10	3	2	Left.
		5	P	7	2	2	Right.
		4	P	3 ?	2	1	?
	First two rows of plates wanting.						

* Interambulacrum wanting at the dorsal portion of the area.

† Interambulacrum complete in the dorsal portion of the area.

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STUDIES OF PALÆECHINOIDEA

BY ROBERT TRACY JACKSON

(Read before the Society, August 27, 1895)

CONTENTS

Studies of the Melonitidæ.

INTRODUCTION.

In the following studies of the several families of the Palæechinoidea it is the intention to take up for consideration the several genera and species in their natural systematic order of sequence as expressed in the proposed new classification (see table facing page 242). This intention is carried out, as far as present knowledge admits, in families succeeding the Melonitidæ. In the present family of the Melonitidæ, however, the rule is departed from, because the genera and species of which fullest knowledge is attained are the more specialized, and the more primitive genera are least known as far as available material goes. In this family, therefore, the genera and species are taken up in the order of convenience for handling the several cases rather than in the proper systematic order. The natural systematic sequence of the genera would be, *Rhoechinus*, *Palæechinus*, *Oligoporus* and *Melonites*, as shown in the table facing page 242. For sources of material, obligations due, and similar statements, the reader is referred to the introductory, page 135, of the preceding paper: "Studies of *Melonites multiporus*." References to this earlier paper are frequently made by page number, without further quotation, in the present paper.

DESCRIPTION OF MELONITES GIGANTEUS, SP. NOV.

Plate 4, figure 19; plate 5, figures 21–24. Table, page 180.

This new species, *Melonites giganteus*, is described from a single individual, which is a truly superb, finely preserved specimen, from the Lower Subcarboniferous of Bowling Green, Kentucky. It is in the collections of the Museum of Comparative Zoölogy, catalogue number 2989. The specimen is entirely silicified. The melon-like form is preserved with hardly any distortion on the oral side (plate 4, figure 19), and on the other side, though somewhat crushed, shows much structural detail. The oral and aboral terminations of the ambulacra and interambulacra are almost perfect in some areas, but orally they are wanting in the first row of plates (plate 4, figure 19); corona very large, exceeding by far any previously described species of the Palæechinoidea; height at the point of greatest dimension, 11.5 centimeters; height from oral to anal area through the exact center, 10 centimeters ; greatest horizontal diameter through the middle of corona, 15.5 centimeters. These measurements are somewhat affected by a slight dorso-ventral compression, which while reducing the height exaggerates the horizontal diameter.

The interambulacra at the widest part measure 4.1 centimeters ; at the narrowest part, at the oral area, where three plates only exist, 8 millimeters. Following the curve of the area in its center, the interambulacra measure 18.7 centimeters in length. At the oral end, as far as preserved, there are three plates in the first row of four of the interambulacra. Passing progressively from this point dorsally, new columns are introduced until we find the greatest number attained, 11, at a point about two-thirds of the distance to the apical pole (plate 5, figure 21). The ambulacra at the ambitus are narrower than the interambulacra, measuring 3.8 centimeters at the widest part, at which area there are 12 columns of quite irregular plates. At the ventral termination the ambulacra are 1.4 centimeters in width, thus surpassing at this point the width of the interambulacra. Ventrally there are but four columns of ambulacral plates (plate 4, figure 19; plate 5, figure 22), as in *Melonites multiporus.* The plates of the test are very thick (plate 4, figure 19), those at the median zone measuring 8.5 millimeters in thickness. The sides of the plates are slightly inclined to allow for mutual contact in a curved test, but are as nearly perpendicular as the case admits. The plates of the adambulacral columns are extended under the adjacent ambulacral plates, as in *Melonites multiporus* (plate 2, figure 5) ; otherwise the plates of *Melonites giganteus* show no tendency to imbrication, and with their thickness emphasize a very considerable rigidity of the test.

The interambulacral areas are very much elevated (plate 4, figure 19) and present a comparatively sharp angle where the sides dip down to meet the ambulacra. The ambulacra are sharply elevated in the median portion, depressed on the lateral borders. The elevations of these areas extend beyond those of the interambulacra in a peripheral line and give the Echinus a melon-like form in a very accentuated degree.

The two adambulacral columns of interambulacral plates are pentagonal, as in other species of the genus, and are crenulated on their outer borders (plate 5, figures 21 and 22) by impact with adjacent ambulacral plates, 3 of which commonly abut against each interambulacral plate. The plates of the median interambulacral columns are hexagonal, excepting the terminal plates of columns as added, which are pentagonal, and adjacent heptagonal plates ; also excepting the newly added dorsal rhombic plates and such others as are described in the detailed consideration of this area.

In the ambulacral areas the plates are, for the most part, ambiguous, as is the common condition in specimens of *Melonites.* From the small size and irregular outline of the plates, their contours are largely destroyed by the process of silicification. Starting with 4 plates at the ventral end (plate 5, figure 22), new plates and new columns are progressively added, as in *Melonites multiporus** (plate 2, figure 4), until in the middle of the corona 12 columns were observed. At this region no area was sufficiently clear to be figured, so that in representing the ambulacrum (plate 5, figure 24) I was obliged to select an area considerably below the median zone which had not acquired the full complement of 6 columns characteristic of each half-ambulacrum in later stages. The portion selected for the detailed figure of the ambulacrum is indicated in plate 4, figure 19, by the letter *X* in area *B*. At the area marked by *Y*, just above this point, by close inspection the outline of 6 plates may be made out in this half-ambulacrum.

It is possible that a specimen more perfect in ambulacral detail might show still more columns added in a higher zone. The plates of the two median columns of the ambulacra *a′ b′* are very large (plate 4, figure 19, and plate 5, figure 24), and the pores in these, as in other plates of the area, exist in the part of the plate lying nearest the interambulacra, as in *Melonites multiporus.* All the plates observed possess two pores. The plates of the ambulacra and interambulacra are thickly studded with tubercles that formed the base of attachment of spines (plate 5 figure 23; also seen in plate 4, figure 19). There are about 25 such tubercles on the larger interambulacral plates, but no spines are preserved. There are obscure traces of genital and ocular plates, but no details of form or structure were made out.

The interambulacrum of *Melonites giganteus* is interesting as a study on account of the great number of plates and columns existent and for a comparison of the arrangement of the same with other Palæechinoids. The most perfect area in the specimen, which by the adopted notation is designated as *A*, is illustrated by Mr Emerton's very skillful drawing in plate 5, figures 21 and 22. It is also well shown up to and including the introduction of the ninth column in plate 4, figure 19. The arrangement of this same area is also represented, together with the arrangement of the other 4 interambulacral areas, as far as they can be ascertained, in the table (page 180). This table is a graphic proof of the perfection of the specimen, as in it we are able to tabulate the essential details of no less than 42 columns of plates throughout their entire length. In many portions, where the surface was eroded, the form of the plates could yet be ascertained by the middle, or lower proximal portion of the plates, which

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*On account of imperfections from silicification the transition is not shown so clearly as in the figure cited, but enough is visible to prove the similar method of introduction.

were still existent. In the area figured all the plates were preserved entire, excepting where vacancies are shown.

At the ventral termination of the area, plate 5, figure 21, there is a row of 3 plates. This area is also shown as area *A* in plate 4, figure 19. The median plate 3 is hexagonal and is the initial plate of column 3, the first formed column of median hexagons. Column 3 obviously originates with one adambulacral column on either side, the universal position of this column. Studying this first row, it is seen that on the ventral border the median plate presents an angle; the two lateral plates a comparatively straight edge (plate 5, figure 22). This form of outline corresponds with that seen in *Melonites multiporus* at the ventral border of area *E* (plate 2, figure 2). It consequently corresponds with the ventral termination of the second row of that species, as shown in area *A* (plate 2, figure 2); also the similar area of *Oligoporus coreyi* (plate 6, figure 25). From this evidence it is unquestionable that the first row of plates, in the specimen of *Melonites giganteus*, is absent from separation of the same after the death of the individual. The same feature is seen at the base of 4 areas, *A*, *C*, *G* and *I*, as shown in plate 4, figure 19; but area *E* is less perfect ventrally (see table, page 180).

This first row of interambulacral plates could not be absent from resorption during life by enlargement of the peristome in *Melonites giganteus*, as discussed in *Archæocidaris*, on page 215, because in that case the ventral border would probably present a straight line, as in *Melonites multiporus* (plate 2, figure 3). The two lateral plates, numbers 1 and 2, at the ventral border are therefore the second plates in their columns and form the base of the two columns of adambulacral plates. In the reconstruction of the base (plate 5, figure 22) the ventral plates of the two lateral columns are shown at 1 and 2, as indicated by dotted lines, succeeded by plate 3 and its adjacent plates, which are the first plates shown in the specimen (plate 5, figure 21). The angulated ventral face of this first row would in itself indicate the absence of at least one row, but taken in conjunction with the studies of the same areas in *Melonites multiporus* and *Oligoporus coreyi* the evidence is incontrovertible.

The fourth column is introduced in the next row above the third by the terminal pentagon 4 (plate 5, figure 21). At its origin it has one column on the left and two on the right, being thus one column too far to the left by our law of alternation. In areas *C*, *E*, *G* and *I* (plate 4, figure 19), however, it occupies its normal position, with two columns on the left and one on the right. A similar variation is shown in *Melonites multiporus* (area *I*, plate 2, figure 2). In 4 of the 5 areas in which this plate is shown in *Melonites giganteus*. it occupies the normal position, as shown in the table, page 180. It is to be noted that this column 4 is the only one in plate 5, figure 21, which does not accord with the law of alternation in the introduction of successively added columns. Plate 4 truncates the dorsal border of initial plate 3 of column 3, inducing a hexagonal form in this plate, as shown also in *Melonites multiporus* (plate 2, figures 2 and 3) and *Oligoporus* (plate 6, figure 25). The same condition of affairs existed in 3 other areas (table, page 180).

Column 5 is introduced in the second row after 4 by the terminal pentagon 5. At its point of origin this column has two columns on either side, the normal position. It has a heptagonal plate on its left ventral border. *Melonites giganteus* is later discussed as an extreme member of the genus on account of its great number of columns of plates, and in this early introduction of the fifth column there is an interesting bit of correlative evidence. Extreme types are quite commonly highly accelerated in their development, early acquiring features usually appearing at a later stage in less specialized, more primitive allies. Cases of such acceleration are seen in *Nautilus*, *Baculites*, *Spondylus* and *Discinisca*.* Here in *Melonites giganteus* we have the fifth column originating earlier than the same column in the more primitive † types, *Melonites multiporus* (plate 2, figure 2) and *Oligoporus coreyi* (plate 6, figure 25).

The sixth column is introduced by the terminal pentagon 6 (plate 5, figure 21). At its point of origin it has 3 columns on the left and 2 on the right, its usual position. A heptagonal plate, *H*, lies on the left ventral border of pentagon 6. In two other interambulacral areas, *E* and *G*, column 6 originates as in this area *A*; but in two areas, *C* and *I*, the column originates one column farther to the left with a heptagon on the right (plate 4, figure 19, and table, page 180). The seventh column begins with pentagon number 7, having a heptagonal plate on its right ventral border. This column at its point of origin has 3 columns on either side. Comparing this with the same plates in the other areas we find (plate 4, figure 19, and table, page 180) the same arrangement in areas *G* and *I*. In *C* the arrangement is the same except that the heptagon is on the left side of the pentagon. In area *E* the column originates one column too far to the right, so that there are 4 columns on its left and two on its right, the heptagon lying on the left of the pentagon. This irregular position of odd-numbered columns is of very rare occurrence, having been observed in very few specimens in my researches on this family,‡ namely, in *Melonites multiporus* (numbers 3023, 3021, 3016, 3004 and 2992 in the tables, on pages 165–170) and a specimen of the same species observed at Princeton (see page 153). It is somewhat remarkable in these 7 cases

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*As shown by Hyatt, Brown, Jackson and Beecher.

† More primitive according to the views expressed in this paper (see page 199).

‡ An irregular position of column 5 is figured in *Lepidesthes coreyi* by Meek and Worthen. (See remarks on that species, page 209.)

that the irregularity should have occurred in the seventh or ninth column. A still further irregularity of the seventh column is described under *Melonites septenarius* (plate 9, figure 49).

The eighth column originates in pentagon 8, with a heptagon on its left and with 4 columns on the left and 3 on the right, thus being in its correct theoretical position. Comparing with plate 4, figure 19, and the table on page 180, we find that areas *E* and *G* are as described, except that *E* has the heptagon on the right instead of on the left. Areas *C* and *I* have column 8 one place too far to the left, having 3 columns on the left and 4 on the right, and the heptagon of *C* is on the right. The ninth column begins in pentagon 9 (plate 5, figure 21) with 4 columns on either side, as in *Melonites multiporus* (plate 5, figure 20) and *Oligoporus* (plate 6, figure 34). The plates below pentagon 9 in *Melonites giganteus* present a peculiar arrangement unlike anything seen in any other specimen of the Palæechini. Bordering on the pentagon ventrally are two heptagons, *H H';* below *H* there is a third heptagon, *H''*, and these 3 heptagons with the hexagon *A*, enclose a rhombic formed plate. A similar condition of affairs exists in the same relation to pentagon 9, in areas *C*, *E* and *I* (plate 4, figure 19, and table, page 180). It is elsewhere stated that the plates of the median columns are all hexagonal or its equivalent as a dynamic consequence of the conditions of lateral pressure. This is an excellent proof of the principle, for the extra side of one heptagon, *H*, compensates for the loss of one side in pentagon 9; the two other heptagons, *H' H''*, by their two added sides compensate for the absence of two sides in the enclosed four-sided plate. The enclosed rhombic plate, it is seen, terminates ventrally in an angle; the only plates normally doing this are terminal pentagons.* This plate, therefore, is considered as really the first formed plate of column 9 which has become separated from its next dorsal successor, which is pentagonal plate 9. Another case seen of a plate being separated from its successor dorsally is that shown in the ninth column of *Oligoporus danæ* (plate 6, figure 31), where the terminal pentagon has become separated from the next plate of its column. The only other cases seen of plates of a column being separated dorso-ventrally (except near the dorsal pole, where separation normally occurs, plate 3, figure 13) are in the sixth column of *Oligoporus missouriensis* (plate 9, figure 50) and the seventh column in area *I* of *Rhoechinus gracilis* (plate 7, figure 36).

Apparently this separation of the rhombic plate of *Melonites giganteus* (plate 5, figure 21) is a case of slightly arrested development in the ninth column—that is, after the first plate was formed, the rhombic one, no

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*Excepting, of course, rhombic plates near the dorsal area, where the form is otherwise accounted for.

new plate was added in the next formed row, while plates were added in the several other adjacent columns; when the second row was formed above the rhombic plate a new plate was again added in column 9, but being separated from its ventral predecessor it formed a pentagon. This view appears correct from the fact, strongly brought out in these studies, that accessory or adventitious plates are unknown in the Melonitidæ, all the plates in every specimen seen being distinctly associated with others in definite columns. One area, *G*, does not show the peculiarity of the rhombic first formed plate as discussed and which is existent in 4 areas, *A*, *C*, *E* and *I* (table, page 180).

Up to the ninth column the arrangement of plates in *Melonites giganteus* can be compared with the similar arrangement in *Oligoporus danæ* (plate 6, figures 31 and 34); also frequently with specimens of *Melonites multiporus* (plate 5, figure 20). Above this point, however, it exceeds the number of columns of interambulacral plates of any other species of the Melonitidæ. The tenth column originates in pentagon number 10, with a heptagon on its right (plate 5, figure 21). Column 10 at its point of origin has 5 columns on the left and 4 on the right. Comparing this with the table (page 180), it is seen that the tenth column is similar in position in areas *E*, *G* and *I;* the position of the heptagon, however, varies, being on the left in area *I.* The tenth column is broken away in area *C.* The eleventh column originates in pentagon 11, with a heptagon, *H*, on the right. This column at its point of origin has 5 columns on either side. It is, therefore, as well as column 10, in its correct theoretical position, as deduced from the law of growth of interambulacral areas. Turning to the table on page 180, it is seen that the eleventh column is wanting in one area, *C.* In 3 areas *A*, *E* and *I*, it occupies the same position and terminates as in plate 5, figure 21. In area *G* it originates one column too far to the right. The position of the heptagonal plate in all these areas is on the right,* its usual position in odd-numbered columns. In the sixth plate, in column 11 (plate 5, figure 21), a peculiar pentagonal plate, *N*, occurs. This plate is noteworthy on account of its pentagonal form, for it is not a terminal plate of a column.

Progressing dorsally, we find in an area equal to about one-sixth the whole length of the interambulacrum that there is a gradual passage from hexagons to plates of a more or less rhombic form, as in *Melonites multiporus* (page 149). These young plates have a progressively shorter line on the upper and lower sides and are relatively longer dorso-ventrally than the older hexagonal plates. This change may be seen in plate 5, figure 21. There is not so much drawing out and separation of the plates as in the same area of *Melonites multiporus* (plate 3, figure 13, and plate 5,

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* Excepting area *G*, where, owing to imperfections, its position was not ascertained.

figure 20). This may be a specific or simply individual difference, or even a difference due to the age of the individual. There is a very distinct dropping out of the middle and last added column, number 11. This column is reduced to a tiny rhombic plate at its upper limit, and is not represented at all in the last rows built by the echinus as far dorsally as they can be traced. On the other hand, the last (eighth) column in *Melonites multiporus* extends directly to the genital plate (plate 3, figure 13). It is an axiom of old age characters that the last features acquired are soonest lost, and it seems that this specimen of *Melonites giganteus* had entered on its decline, which is shown by the dropping out of a column that at a little earlier period in growth must have been continuous to the genital area. During later growth, had such taken place, this last column apparently would not have been existent, so that the individual in its decline has virtually resumed the condition of building only 10 columns of plates, a feature which was initiated at a relatively early age, as shown by pentagon 10, plate 5, figure 21 (see page 150). There is a distinct inequilaterality of the interambulacrum near the dorsal area, as shown in plate 5, figure 21. Columns 9 and 10 are quite alike on the two sides of the center, but columns 7 and 8 are, on the contrary, very unlike, as are also columns 5 and 6.

In each of the 5 interambulacral areas of *Melonites giganteus* the several columns, as demonstrated in the fourth column of the table (page 180), made their appearance at exactly or nearly the same horizon. The greatest exactitude in the period of introduction is maintained in the earliest added columns, especially numbers 3, 4, 5, 6, and 7, while in the columns appearing last there is more variation, as might be reasonably expected. Stating the case briefly, in all areas the third column originates in the second row and the fourth column in the third row, as in *Melonites multiporus.* The fifth column originates in the fifth or sixth row; the sixth column in the eighth row; the seventh column in the tenth or eleventh row; the eighth column originates in the twelfth to fourteenth row; the ninth column originates in the sixteenth or seventeenth row; the tenth column originates in the twentieth to twenty-third row, and the eleventh column originates in the twenty-fifth to the twenty-ninth row. Comparing this result with that shown in *Melonites multiporus*, where it has been ascertained in a large number of specimens (page 162), we find that after the fourth column each of the later added columns originated much earlier in *Melonites giganteus* than in *Melonites multiporus.* This species, therefore, is not only furthest advanced in the special line of variation of the genus, but it is also highly accelerated in its development, very early passing through those stages seen in later growth in less specialized members of the genus.

Table of Plate Arrangement of Melonites giganteus, sp. nov.

Melonites giganteus, sp. nov.	Number of columns in the area.	Column number.	Terminates ventrally.	Originates in row from base.	Columns on left of, at origin.	Columns on right of, at origin.	Heptagon on left or right of terminal pentagon.
Interambulacrum A † (This area is figured on plate 5, figure 21.)	11	11	P	28	5	5	Right.
		10	P	21	5	4	*Right.*
		9‡	P	17	4	4	Right.
		8	P	14	4	3	Left.
		7	P	10	3	3	Right.
		6	P	8	3	2	Left.
		5	P	5	2	2	*Left.*
		4	P	3	*1*	*2*	Truncates initial plate 3.
		3	X	2	1	1	....
	First row of plates wanting.						
Ambulacrum B	Four columns of plates at base.						
Interambulacrum C *	....	9‡	P	16	4	4	Right.
		8	P	13	*3*	*4*	*Right.*
		7	P	10	3	3	*Left.*
		6	P	8	*2*	*3*	*Right.*
		5	P	6	2	2	*Left.*
		4	P	3	2	1	Truncates initial plate 3.
		3	X	2	1	1	....
	First row of plates wanting.						
Ambulacrum D	Four columns of plates at base.						
Interambulacrum E †	11	11	P	29	5	5	Right.
		10	P	23	5	4	(?) Broken away.
		9‡	P	17	4	4	(?) Broken away.
		8	P	12	4	3	*Right.*
		7	P	10	*4*	*2*	*Left.*
		6	P	8	3	2	Left.
		5	P	5	2	2	Right.
		4	P	3 ?	2	1	....
	First two rows of plates wanting.						
Ambulacrum F	Four columns of plates at base.						
Interambulacrum G †	11	11	P	27	*6*	*4*	(?) Broken.
		10	P	21	5	4	(?) Broken.
		9	P	16	4	4	Right.
		8	P	14	4	3	Left.
		7	P	11	3	3	Right.
		6	P	8	3	2	Left.
		5	P	6	2	2	Right.
		4	P	3	2	1	Truncates initial plate 3.
		3	X	2	1	1	....
	First row of plates wanting.						

* Interambulacrum incomplete at dorsal portion of area.
† Interambulacrum complete at dorsal portion of area.
‡ See foot-note, page 181.
P = Pentagon. X = Hexagon.

Table of Plate Arrangement of Melonites giganteus, sp. nov.—Continued.

Melonites giganteus, sp. nov.	Number of columns in the area.	Column number.	Terminates ventrally.	Originates in row from base.	Columns on left of, at origin.	Columns on right of, at origin.	Heptagon on left or right of terminal pentagon.
Ambulacrum H	Four columns of plates at base.						
Interambulacrum I †	11	11	P	25	5	5	Right.*
		10	P	20	5	4	Left.
		9‡	P	17	4	4	Right.
		8	P	14	*3*	*4*	Left.
		7	P	10	3	3	Right.
		6	P	8	*2*	*3*	*Right.*
		5	P	5	2	2	Indistinct.
		4	P	3	2	1	Truncates initial plate 3.
		3	X	2	1	1	....
	First row of plates wanting.						
Ambulacrum J	Four columns of plates at base.						

In the interambulacrum *A* (plate 5, figure 21), in column 1, from the ventral to the dorsal end, as far as preserved, 29 plates may be counted ; in column 2, there are 34 plates. If column 1 were as perfect dorsally as column 2 there would without doubt be 34 plates also. Column 3 has 35 plates, column 4 has 33 plates, column 5 has 33 plates, column 6 has 30 plates, column 7 has 28 plates, column 8 has 25 plates, column 9 has 23 plates, column 10 has 19 plates, and column 11 has 12 plates. Adding these, there are seen to be 301 plates existent in the interambulacrum (plate 5, figure 21), or, adding the 9 plates wanting in the first column, 310 plates in all. Supposing the other 4 areas to have approximately the same number, as is the fact, then the interambulacral plates of this specimen are no less than 1,550 in number, to which may be added the two ventralmost plates wanting in each area and a few dorsal plates not preserved clearly enough to be made out.

It is believed that the columns of ambulacral and interambulacral plates as introduced represent stages in growth, as discussed in the section "General Results and their Bearing." Assuming this to be correct, then *Melonites giganteus* when young had 4 columns of ambulacral plates,

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* But not in next column. Compare with heptagon H, associated with pentagon 8, of plate 2, figure 7.

† Interambulacral complete at dorsal portion of area.

‡ Terminates with accessory heptagons and tetragonal plate, as shown at this area in plate 5, figure 21, and plate 4, figure 19. There is no similar peculiarity about pentagon 9 in area G.

as shown by the ventral area of the same. In this feature it, as well as *Melonites multiporus*, is like the adult of *Oligoporus;* later these columns increase to 12. This is a higher number than is attained by any other species of the genus except *Melonites etheridgii*, W. Keeping* (see systematic table facing page 242). In the adult, *Melonites giganteus* has more columns of interambulacral plates than *Melonites multiporus* or any species of the genus. It may, then, in this salient feature be considered the extreme species of the genus, being furthest removed from the ancestral stock, which must have had relatively few columns, as evidenced by the stages in growth through which it has passed. To put it in other words, when very young it had at most 3 columns, then 4, like *Melonites dispar*, (Fischer), and next 5 columns, which is characteristic of adult *Melonites crassus*, Hambach; when older still it had 7, then 8, like adult *Melonites multiporus;* later 9 columns like extreme cases of *Melonites multiporus;* finally it goes ahead of anything found in other species, and has 10 and 11 columns.†

In the accompanying table are shown the relations and form of the plates in the several interambulacral areas of our specimen as far as they could be ascertained. In studying this table comparison is requested with the figures of this species, with the tables of *Melonites multiporus* (pages 165–170; see also page 161), and with the figures of other species and genera of Paleozoic echinoids illustrated in the accompanying plates; also it should be considered in connection with the systematic table of classification of Paleozoic Echini, facing page 242.

DESCRIPTION OF MELONITES SEPTENARIUS, SP. NOV. (R. P. WHITFIELD).

Plate 9, figure 49.

In the American Museum of Natural History in New York, there is a specimen of *Melonites* from the Warsaw group, Subcarboniferous, of Buzzard Roost, Franklin county, Alabama, lower limestone. No specimens of *Melonites* have been previously recorded from the Subcarboniferous of the south Atlantic states. This species differs from any previously described, and for it Professor R. P. Whitfield suggests the name *Melonites septenarius*, the name indicating the number of columns of plates in the interambulacral area. The specimen (plate 9. figure 49) is a silicified cast from the interior, but in parts shows the original thickness of the

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*The type of this species is in the Museum of Practical Geology, Jermyn street, London.

†In the collections of the Wagner Free Institute at Philadelphia there is a specimen, catalogue number 5255, which is ascribed to the species *Melonites giganteus*. It is from the Sub-carboniferous of Tennessee. The specimen, which is fragmentary, corresponds in details of size and proportions with the type. In the ambulacrum there are 12 columns of plates, but in the interambulacrum there are but 9. Ten rows of plates are added, after the introduction of the ninth column, without the introduction of a tenth column. This fact is a striking difference from the type, as described above.

plates. It is a small species, being one of the smallest known. It is not perfect ventrally; but the height of the test as far as shown is 4 centimeters.

The ambulacral plates are not well preserved, but can be made out in places. In the ambulacrum on the right of the figure there are 4 columns of plates at the ambitus in a half area. This shows that the species is characterized by 8 columns of ambulacral plates—an unusual number in the genus. Two pores exist in each plate. The width of the ambulacrum at the ambitus is 1.3 centimeters, narrowing toward the dorsal area.

The interambulacrum ventrally has, as far down as preserved, 6 columns of plates. A seventh column is introduced by the pentagonal plate 7, with a heptagonal plate, *H*, on its left. This seventh column at its point of origin is remarkable in that there are 5 columns on the left of it and only 1 on the right. Odd-numbered columns commonly originate in a median position, with an equal number of columns on either side. Rarely exceptions are found, as shown in the tables of *Melonites multiporus* (pages 165–170), in which, in several cases, an odd-numbered column originates to the right of the center, with one more column on the left than on the right; but no case has been observed in any Palæechinoid other than the present one in which any greater degree of irregularity existed. This interambulacrum is also peculiar in that a plate, *P*, normally hexagonal, is pentagonal in outline, and an adjacent plate, *A*, is heptagonal. No other case of irregularity quite like this has been seen in any of the Melonitidæ. Toward the dorsal termination of the area the interambulacral plates make an approach to the rhombic form seen in other species (plate 3, figure 13; plate 5, figure 21). The width of the interambulacrum at the ambitus is 2.3 centimeters. The interambulacrum is quite elevated in sectional outline, but presents a continuous curve rather than almost an angle on its lateral borders, as in *Melonites giganteus* (plate 4, figure 19).

The nearest ally of *Melonites septenarius* is *Melonites indianensis*, Miller and Gurley* (34). It differs from that species in the proportionately much narrower ambulacra, in having 7 instead of 6 columns of interambulacral plates, and in the gently curving, rather than strongly melon-like form of the corona.

The number of columns of ambulacral plates is an important feature in classification, and the question comes up whether species having eight columns, as *Melonites indianensis* and *septenarius*, should be separated generically. We think not, because in the genus *Melonites* the number of columns of ambulacral plates is quite a variable feature, as shown in the

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*The type of this species is in the private collection of Mr Wm. F. E. Gurley, of Springfield, Illinois.

several species (table facing page 242). One species, *M. dispar*, has but 6 columns; another, *M. giganteus*, has 12 columns, and one, *M. etheridgii*, has 12 or 14 columns of plates; also, while *Melonites multiporus* has 10 columns of ambulacral plates as the feature of the species, it may be that some specimens may only show 8 columns throughout the area. In this species, in one specimen figured (plate 5, figure 20) only 8 columns of plates exist at the ambitus (as shown in the lower portion of the ambulacrum figured), whereas a little further dorsally (in the upper portion of the ambulacrum figured) 10 columns may be counted. These two last added columns in this specimen are added later than usual, and it is conceivable that in some cases they might not be added at all.

CONSIDERATION OF *OLIGOPORUS* AND COMPARISONS OF THE SAME WITH *MELONITES*.

DESCRIPTION OF OLIGOPORUS MISSOURIENSIS, SP. NOV.

Plate 9, figures 50–52.

A fine new species of *Oligoporus* has recently come to hand from the Subcarboniferous of Webb City, Missouri. The exact horizon from which this specimen came is somewhat uncertain, but Dr C. R. Keyes, chief of the Missouri Geological Survey, kindly informs me that it is in all probability from the Augusta limestone. To this species I would give the name *Oligoporus missouriensis*, which is appropriate in recognition of the fact that this state has yielded such rich material for the elucidation of the complex structure of Paleozoic Echini. The specimen is a silicified cast free from matrix and is very slightly compressed. It is in the collection of the Museum of Comparative Zoölogy, catalogue number 3078.

The specimen measures 9 centimeters in height through the dorso-ventral pole; it is somewhat compressed, so that the dorso-ventral measurement is slightly exaggerated; greatest width through the ambitus in the plane of compression, 9.6 centimeters; width at right angles to plane of compression, 7 centimeters. The outline of the test presents an even, almost continuous, curved outline, the ambulacral and interambulacral areas presenting very little elevation beyond the outline of the whole.

The ambulacra consist of 4 columns of low plates in each area; width of ambulacra at ambitus, from 1.4 to 1.6 centimeters, narrowing at the dorsal area. Accessory plates, as seen in *Oligoporus danæ* (plate 6, figure 30), not present. Two pores are in each plate. The spinose projections of the specimen which represent the ambulacral pores lie near the middle of each half ambulacral area (plate 9, figures 50 and 51). This is attributed to the fact that the specimen is an internal cast, and that the pores pass toward the center of the half-areas in traversing the thickness of the plates, although on the outer or distal side of the plates they probably existed in that portion of the plate which was nearest the interambulacra, as in *Oligoporus danæ* (plate 6, figure 30). A similar condition of pores in the center of each half-ambulacrum is shown in the view from the interior, or proximal side, of *Oligoporus coreyi* (plate 6, figure 25). In *Melonites multiporus* the ambulacral pores in traversing the thickness of the plates pass toward the center of the ambulacral area instead of each half-area, as shown in plate 2, figure 5 (see page 141).

In *Oligoporus missouriensis* about 5 ambulacral plates are apposed to each interambulacral plate. The ambulacral plates are more regular in outline than in any other species of the genus seen. One peculiarity not seen in any other Paleozoic echinoid, is the fact that ambulacral plates which lie opposite the horizontal sutures between interambulacral plates are spread out in a fan-like fashion on the outer border, as shown in the figure.

Interambulacral areas measure about 4.1 centimeters in width at the ambitus, narrowing toward the poles. Adambulacral plates are rounded on the ambulacro-interambulacral suture. There are 6 columns of interambulacral plates at the ambitus, and no more are added in the dorsal portion. The sixth column in area *A* is introduced by the pentagonal plate 6, which is discontinuous from the next plate, 6′, of its series, as in the ninth column of *Melonites giganteus* (plate 5, figure 21). Around this plate, plate 6, there is an unusual arrangement of plates. A pentagonal plate, *P*, lies on its left border, and an octagonal plate, *O*, by its two added sides, compensates for the loss of two sides in plates 6 and 6′. The sixth column starts a second time in pentagonal plate 6′ and adds a second plate on the dorsal border of it. Then the sixth column dies out and is seen no more in this area (see page 150). To take up the space where this column has dropped out there is an enlargement and irregular arrangement of plates in the fifth and fourth columns. The plates *P′ P″ P‴*, in column 5, which should be hexagonal, take on a pentagonal form, and one plate, *H*, of column 5 is heptagonal and extended to the right so as to cover the dorsal border of the last formed plate of column 6. Besides these, to compensate for loss of sides in the pentagons, there is a heptagonal plate, *H′*, in column 4 and another heptagonal plate, *H″*, in column 3. This is one of the most unusual irregularities seen in any Paleozoic Echinoid, but it is all in accordance with the laws of growth when the mechanical conditions are ascertained. Two other interambulacral areas, *E* and *G*, not shown in the figure, have a similar dying out of column 6. No other case has been seen in any type of a column originating comparatively early in the life of the individual and then dying out after building a few plates, except as shown in *Lepidesthes wortheni* (plate 9, figure 53). One of the interambulacral areas, *C*, has only 5 columns as the greatest number, and this abortive introduction of a sixth in three areas shows that 6 columns have not become a fixed specific character. Another specimen has 5 columns in all 5 areas. One interambulacrum, *I*, is too imperfect for details to be ascertained. Four columns of plates are made out at the ventral border of the interambulacra as far as they can be traced, but the specimen is imperfect at the lower portion of the corona. New columns of plates are introduced by pentagonal plates with adjacent heptagonal plates, as described in the several species of *Melonites* and in *Oligoporus coreyi* and *O. danæ*. Dorsally the newly added plates are more or less rhombic, as in *Melonites* and *Oligoporus danæ* (plate 6, figure 34). Surface ornamentation of plates is like plate 6, figure 35.

Part of the genital and ocular plates are preserved, and this is important for comparison with the only other species of the genus *Oligoporus nobilis*, Meek and Worthen, in which they have been observed. In *Oligoporus nobilis*, according to Meek and Worthen (31), 3 genital plates showed 5 pores, while 2 showed 4; the ocular plates are stated as imperforate. In *Oligoporus missouriensis* (plate 9, figure 52) the form of the genitals and oculars is the same as in *Melonites* (plate 3, figure 13). Two genitals have 4 pores and one 3, instead of 5 and 4, as in *Oligoporus nobilis*. The two oculars preserved are imperforate, as in that species and *Melonites*, and reach to the periproct.

Oligoporus missouriensis differs from *Oligoporus coreyi* (plate 6, figure 28), which has 6 columns of interambulacral plates, by its more massive proportions; also by the smaller relative size of ambulacral plates, more abutting against an interambulacral plate than in *Oligoporus coreyi*. It differs from *Oligoporus blairi*, Miller and Gurley (34), in the same features; also in being nearly circular instead of melon-like in form, as in that species. It differs from all species of *Oligoporus* or *Melonites* seen or described, in the nearly circular form and in the fact that the interambulacral plates at the junction with the ambulacra present a gently curving outline much as in *Archæocidaris* (plate 8, figure 43), instead of an indented sutural line, as in *Oligoporus danæ* (plate 6, figures 30 and 31); also in the peculiar fan-like form of certain ambulacral plates, as described.

DESCRIPTION OF OLIGOPORUS COREYI.

Oligoporus coreyi, Meek and Worthen (32), has never been figured, but was described by its authors from a single specimen from the Keokuk group of Crawfordsville, Indiana. A specimen in the collections of the Museum of Comparative Zoölogy (catalogue number 3008), after careful study, is referred to this species. This specimen (plate 6, figures 25, 28 and 29) agrees with the description of *Oligoporus coreyi* in the following characters: Body small. globose, moderately thick plates; interambulacra twice as broad as ambulacra; ambulacra composed of 4 distinct columns of plates; interambulacra in the middle composed of 6 columns of plates; pores of the ambulacral plates situated near the outer edge. The pores are near the center of each half-area in plate 6, figure 25, but that is because the specimen is viewed from the inner or proximal side of the test and the pores pass toward the center of the half-area in traversing the thickness of the plate (see *Oligoporus*, plate 9, figure 50; see page 184). The height of Meek and Worthen's type was 1.65 inches; the specimen here described, as far as preserved (plate 6, figure 28), measures 1.87 inches in height. If perfect dorsally, it would probably add at least half an inch to this measurement. If the type was a reasonably entire specimen, which is not stated, our specimen would probably be a little longer in the dorso-ventral axis. The type is stated as being about two inches in breadth and the interambulacra are stated as twice the width of the ambulacra. The authors do not say what the width of the ambulacra and interambulacra is, but we can estimate these areas approximately from their measurement of the breadth. If the breadth. which is two inches, represents fairly the diameter, as may be assumed, then the circumference may be attained by multiplying the diameter, 2 inches, by 3.14, which gives 6.28 inches, or 15.8 centimeters, for the circumference. As the ambulacra are half the width of the interambulacra, therefore the width of the ambulacra must be one-fifteenth of the circumference, or 1.05 centimeters; the width of the interambulacra would be twice that amount, or 2.1 centimeters. Comparing the specimen with this ideal measurement, I find that the ambulacra measure at the widest part 1 centimeter and the interambulacra 1.9 centimeters. These measurements, taken with the number of columns of plates, the inferred size of the plates, etcetera, render it entirely probable that the specimen is *Oligoporus coreyi.* In the type the surface is described as unknown, but in this specimen the plates of the interambulacrum are thickly covered with small bosses for the attachment of spines (plate 6, figure 29). No spines are preserved.

The specimen of *Oligoporus coreyi* here described is labeled as from Indiana, but the label does not give a detailed locality or geological horizon. The specimen is composed of thoroughly crystallized calcic carbonate, which is stained reddish brown with oxide of iron. It differs lithologically from Crawfordsville material and cannot, therefore, be ascribed to that locality. The type was from the Keokuk group, and having no evidence to the contrary this specimen is provisionally ascribed to the same horizon.

The species *Oligoporus coreyi* differs from *Oligoporus danæ* as described in the original publication, which is here confirmed, in being much smaller and apparently more depressed in form; in having more deeply furrowed ambulacral areas,* and also only 6 columns of interambulacral plates. From *Oligoporus nobilis* it differs by its smaller size and more deeply sulcate areas, which are proportionately wider. *Oligoporus coreyi* differs from *Oligoporus mutatus*, Keyes (23), and *O. missouriensis*, Jackson, in having relatively much smaller plates and in being much smaller as a whole; also in being a fine delicate species rather than robust in its proportions; it also has much less of a melon-like rotundity in its areas than *O. mutatus*, as well as one more column of interambulacral plates than that species.

It is shown in echinoids that, as the individual grows, new columns of interambulacral plates are progressively added until the number normal to the species is attained. It may, therefore, be properly questioned whether this specimen is an adult, and not the young of another species as *Oligoporus danæ*, which in later growth, had the animal lived, would have added more columns of plates, and the plates themselves have increased in size. In many cases this might be a difficult question to decide, and it is possible that species of Palæechinoids have been based on immature specimens; but from the very principles of growth involved we find the answer in this case. The first 6 columns of plates are here, as in all other cases studied, introduced comparatively early in the life of the individual, in this case the sixth originating in what is probably the ninth row from the oral end. A seventh row, if it were to be added, should have followed soon after the sixth, as in *Oligoporus danæ* (plate 6, figure 34). In *Oligoporus coreyi* 6 rows of plates are added after the introduction of the sixth column without the appearance of a seventh column; therefore from a comparative study of other related species and genera it can properly be assumed that no more would have been added.

ARRANGEMENT AND DEVELOPMENT OF PLATES IN OLIGOPORUS COREYI.

Turning from the consideration of species characters to that of the arrangement and development of the ambulacral and interambulacral areas of *Oligoporus*, as shown in the specimen of *O. coreyi*. The study of *Oligoporus* and the comparison of its plate arrangement and development with that of *Melonites* is important on account of the evident affiliation of the genera. Adult *Oligoporus* is characterized by possessing 4 columns of ambulacral plates, and sometimes accessory intercalated plates, as described in *Oligoporus danæ*. In the interambulacra of *Oligoporus* there

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*The degree of depression is not shown in our specimen, as it is preserved only as flattened out portions of the test.

are from 4 to 9 columns of plates, varying with the species. It is shown in preceding pages that the young of *Melonites*, as indicated by the ventral portion of the corona, in two species is like adult *Oligoporus* in having 4 columns of ambulacral plates; therefore the ventral portion of *Oligoporus* assumes a special interest, as by it the relations of the two types may be carried back one, two, or even three steps further.

The ventral termination or younger portion of *Oligoporus coreyi* is shown in plate 6, figure 25. First taking up the ambulacral areas, it is seen that the ambulacrum terminates ventrally in two plates, *a*, *b*. The plates do not run directly across the half area as in *Cidaris* (plate 8, figure 48), but slightly overlap one another, as seen more markedly in the ambulacrum of *Rhoechinus gracilis* and *elegans* (plate 7, figures 37 and 40). Passing dorsally, the overlapping of the plates of the ambulacrum in *Oligoporus*, plate 6, figure 25, progressively decreases, passing through a stage which may be compared with the characteristic condition of *Palæechinus* (plate 7, figure 39) until in the tenth row on the right side of the area it is seen that there are two plates, *a*, *a′*, in one-half of the ambulacrum, which interlock at their median points of contact almost exactly as they do in the adult of *Oligoporus danæ* (plate 6, figure 30).

It is observed that the pores of the ambulacral plates in *Oligoporus coreyi* are in the center of the half-areas instead of being close to the interambulacral area, as seen in *O. danæ* (plate 6, figure 30). This is because the specimen is viewed from the inner or proximal side of the test, and the pores in passing through the substance of the plate are inclined, so that while they are toward the interambulacral area on the outer or distal side of the plate on the inner side they appear much nearer the center of each half-ambulacral area (see page 184).

We have in this development of the ambulacrum of *Oligoporus* the highly interesting fact that ventrally the plates of that area are in two instead of four rows, and are in addition closely like the plates of *Rhoechinus;* during growth and before attaining the mature condition they pass through a stage like that characteristic of *Palæechinus;* also the final important fact that the number and arrangement of ambulacral plates of adult *Oligoporus* is like that of the ventral or younger portion of *Melonites* (plate 2, figure 2). As the ambulacral areas are the real feature of generic distinction between *Rhoechinus*, *Palæechinus*, *Oligoporus* and *Melonites*, it is with great satisfaction that I am able to state that the four genera may be most intimately and serially connected by a study of the growth of the ambulacrum. The four genera represent a distinct phylum, which is progressively advancing in the line of increase of columns of ambulacral plates. Etheridge (11) has pointed out already from a consideration of the adult that *Oligoporus* seems to be intermediate between

Rhoechinus, (*Palæchinus*[*]) and *Melonites*, having twice the number of ambulacral plates of the former and less than the latter. His view is fully substantiated by the development.

In *Oligoporus* the development of the two columns of plates in each half ambulacrum from the very early condition of one column of plates, as seen ventrally, may be compared to interlocking one's fingers and then gradually pulling them apart. It is seen from studying the figures that the two columns of plates, *a*, *b*, at the ventral border of *Oligoporus* (plate 6, figure 25) together correspond to the 4 columns of plates, *a*, *a'*, *b'*, *b*, in adult *Oligoporus;* also they are the homologue of the 4 columns, *a*, *a'*, *b'* *b*, at the ventral border of *Melonites* (plate 2, figure 4) and in adult *Melonites* (plate 2, figures 2 and 4, and plate 4, figure 19) they correspond to the two large median columns of ambulacral plates, *a'*, *b'*, together with the two small lateral columns, *a*, *b*. We have then the interesting morphological deduction, figure 1, page 191, that the 4 columns of *Oligoporus* are the equivalent of the two median and two outer columns of ambulacrals in *Melonites*, and that these 4 columns of each genus are traceable to and directly derivable from the two columns of ambulacrals in types like *Rhoechinus* (plate 7, figure 37) and the two plus columns in *Palæechinus*[†] (plate 7, figure 39), or earlier still to the two columns existent in the ancient primitive type *Bothriocidaris*, figure 4, page 234. These 4 columns of *Oligoporus* and *Melonites* also appear to be the morphological equivalent of the two columns of ambulacrals seen in *Archæocidaris* and allies; also modern *Cidaris* and related forms.

Turning to the consideration of the ambulacrum of adult *Oligoporus danæ* (plate 6, figure 30), it is seen that there are 4 columns, *a*, *a'*, *b'*, *b*, of well developed, clearly defined plates. It is also seen at certain points that accessory plates exist between the primary ambulacral plates and close to the middle of each half area. These accessory plates are not regularly distributed excepting in so far as occupying a median position. It seems that in these occasional plates we can see the foreshadowings of additional columns of plates, which, as shown in *Melonites* (plate 2, figures 4 and 2), originate in just this same median position between the outer and median column of each half ambulacral area.

The morphological and genetic relations of the ambulacral plates in these genera are expressed in the accompanying diagram, figure 1, which, with the foregoing description, fully illustrates itself. It is believed that this figure expresses the correct phylogenetic relations of the included

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[*] The species of *Palæechinus* have been divided between the genera *Rhoechinus* and *Palæechinus* by Duncan (8) since Etheridge's paper was published.

[†] In *Palæechinus* there are not 4 fully developed columns, as in *Oligoporus*. It is really a transition condition, and for convenience in this paper the number of ambulacral columns are designated as two plus. See, also, description of this genus, page 205, and the systematic table facing page 242.

genera, for in the interambulacrum a corresponding progressive development occurs as well (see classification in table facing page 242).

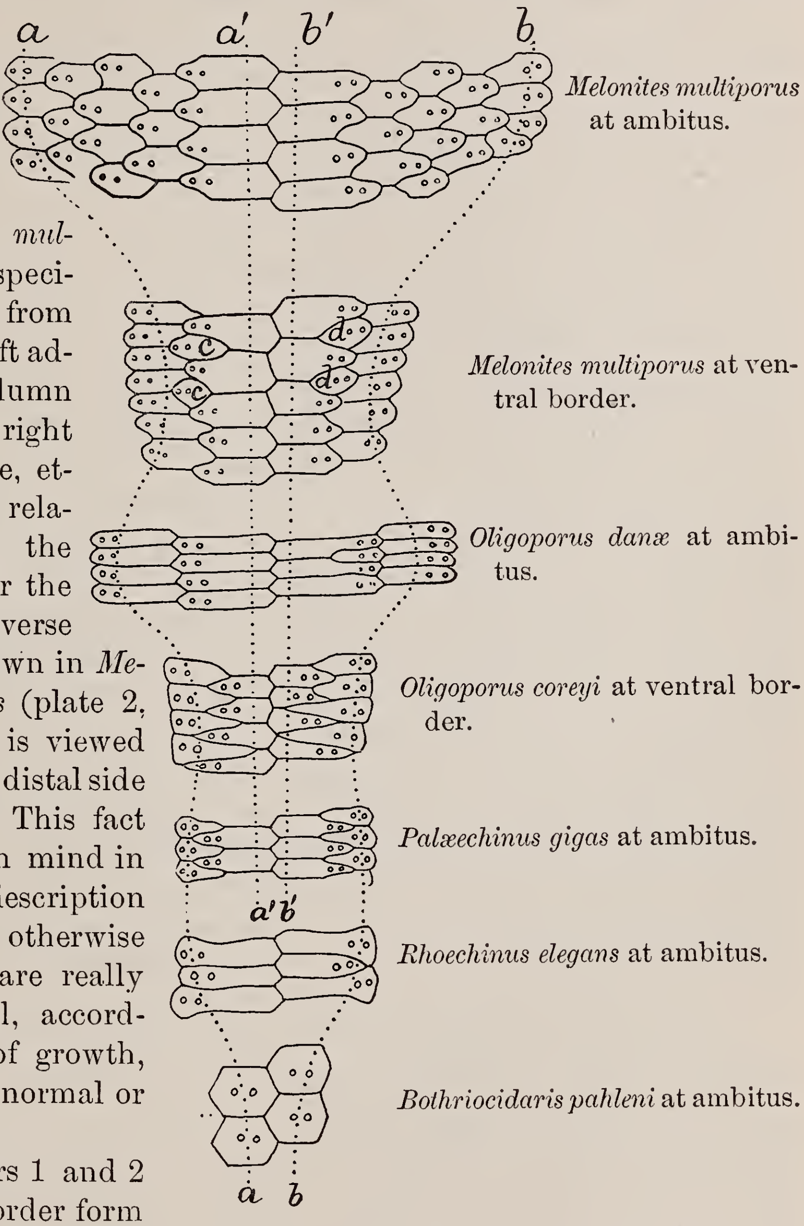

FIGURE 1.—*Relations of the ambulacral Plates.*

The diagram illustrates the relations of the ambulacral plates at the ambitus or the ventral border and ambitus of the several included genera. Compare with figures in plates and figures 3 and 4, page 234, see also page 142.

The interambulacrum of *Oligoporus coreyi* (plate 6, figure 25) terminates ventrally in two plates, 1 and 2, as shown in both areas of the figure, just as previously seen in *Melonites multiporus*. As this specimen is viewed from the inside, the left adambulacral column appears on the right side of the figure, etcetera, and the relative position of the areas appears for the same reason in inverse order to that shown in *Melonites multiporus* (plate 2, figure 2), which is viewed from the outer or distal side of the corona. This fact must be borne in mind in considering the description of the figure, as otherwise features which are really perfectly normal, according to the law of growth, would appear abnormal or reversed.

Plates numbers 1 and 2 at the ventral border form the basis of the two adambulacral columns of pentagonal plates, as in *Melonites*. Plate 1 of the right-hand area is mutilated on its ventral aspect, so that it presents a jagged outline; but plate 2 is entire on its ventral aspect. This plate has an inclined face leading upward from the ventral to its median portion, presenting just such a form as seen in plate 2 of *Melonites multiporus* (plate 3, figure 10). Restoring the broken border of plate 1, as is done in plate 6, figure 26. we see that the two plates by their inclined faces include an angle ventrally, just as in *Melonites multiporus* (plate 3, figure 10). This angle is apparently the space occupied by a missing plate, 1′, which, as a stage in growth, corresponds exactly with a similar stage in *Strongylocentrotus* (plate 3, figure 9), as discussed on page 144. This condition in *Oligoporus* apparently represents a condition in which by the advancing edge of the peristome the ventral border of the interambulacrum has been partially resorbed, so as to cut away a large part of plate 1′ and induce straight edges on a portion of the ventral areas of plates 1 and 2, as in the figures of *Melonites* and *Strongylocentrotus* cited. In plate 6, figure 27, the ventral area of *Oligoporus coreyi* is restored to the condition it probably had before any resorption of the interambulacrum took place. Plate 1′ is there a large pentagonal plate filling the entire ventral area and having the same position and form which the same plate had in *Melonites* as restored in plate 3, figure 11, and in *Strongylocentrotus* (plate 3, figure 8), as observed by Professor Lovén. A similar form and position of this first plate 1′ of the interambulacrum is shown in this paper in *Pholidocidaris* (plate 9, figure 54), *Lepidechinus* (plate 7, figure 42), and *Goniocidaris*, after Lovén (figure 3, page 234). A similar position, but from mechanical reasons a different formed plate, is seen in the first plate, 1′, of *Bothriocidaris* (figure 4, page 234).

In *Oligoporus* this first plate, 1′, from the law of alternation of introduction of columns should be the first member of column 1, the left adambulacral column, as in *Melonites*. By its presence this single plate represents a single column stage seen in the young of the whole class of Echini as maintained by Professor Lovén, and finds its ancestral representative in adult *Bothriocidaris* (figure 4, page 234). The relations and importance of this early single plate stage are discussed under *Melonites*, page 144.

In the next row of plates above 2 and 3 in *Oligoporus* (plate 6, figure 25) we find plate 3, which is hexagonal, and is the initial plate of the first column of median hexagonal plates, exactly as in *Melonites*. In the next row pentagonal plate 4 appears, and it is the beginning of column 4. Its ventral border impinges on the dorsal side of plate 3, inducing thereby the hexagonal form of that plate, just as in *Melonites*. Column 4 at its origin has two columns on the right and one on the left, which, as the specimen is viewed from the inside, is the equivalent of two on the left and one on the right, the normal number as viewed from the outside. Three rows further dorsally the fifth column is introduced by pentagon number 5, with a heptagonal plate, *H*, on its right side (left as viewed from without). This column at its origin occupies a median position, with two columns on either side, as usual. This column originates in the same row as it does in *Melonites multiporus* (see discussion, page 162). The interambulacral area is not preserved above this point.

In a later period of growth, which represents as far as preserved the interambulacrum of adult *Oligoporus coreyi* (plate 6, figure 28), there is at the ventral border a pentagonal plate 4, representing the initial plate of column 4. This column has at its origin two columns on the left and one on the right (as seen by producing ventrally the plates which are missing in column 1 at this point), which is the equivalent of two on the right and one on the left as viewed from the outside. It is, therefore, a left-handed column, as in the same column of area *I* of *Melonites* (plate 2, figure 2). The fifth column is introduced by pentagon 5 in the third row above 4, as in the other area just described. Pentagon 5 has a heptagonal plate, *H*, on its right border (the left as viewed from without). In the third row above 5 the sixth column is introduced by pentagon 6, with a heptagonal plate on its right (left as viewed from without), the normal position. At its origin column 6 has two columns on its left and three on its right, the normal position, when the numbers are reversed for comparison from without. Above pentagon 6, 6 rows of plates are introduced without the appearance of a seventh column, and as the seventh is introduced soon after the sixth in *Oligoporus danæ* (plate 6, figure 34) and all specimens of *Melonites multiporus* and *M. giganteus*, there is in this fact evidence for supposing that no more columns would originate, as previously discussed. The inward curvature of the sides of the interambulacrum in its dorsal portion indicates that it is relatively near what was the dorsal termination of the area, so that if any more columns were present in the specimen when entire, they must have originated quite close to the genital area, as seen in the ninth column of *Rhoechinus gracilis* (area *C*, plate 7, figure 36).

DESCRIPTION OF PLATE ARRANGEMENT IN OLIGOPORUS DANÆ.

Oligoporas danæ, Meek and Worthen, of the Keokuk group has been described only by the authors (30) in their original publications on the species. I am therefore able to add some new features to the present knowledge of the species, as well as to make comparisons of its plate arrangement with that of *Melonites*.*

A specimen of *Oligoporus danæ* in the collections of the Museum of Comparative Zoölogy (catalogue number 2997) shows nearly the whole of an interambulacrum above the ventral portion, as well as the ambu-

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*The types of *Oligoporus danæ* and *O. nobilis* are in the Worthen collection in the University of Illinois, at Urbana, Illinois (see foot-note, page 136). The types of *Oligoporus bellulus*, *blairi* and *sulcatus* are in the private collection of Mr Wm. F. E. Gurley, of Springfield, Illinois, as I am informed by that gentleman.

lacra on either side. The adambulacral plates are inclined under the adjacent ambulacrals, as in *Melonites multiporus* (plate 2, figure 5); otherwise there is no imbrication, but interambulacral plates are inclined slightly upward and outward on all sides, as usual in hexagonal plates of this group.

At the ventral end of this specimen, as far as preserved (plate 6, figure 31), there are 6 columns of plates, the left adambulacral being produced mentally. The adambulacral columns are composed of pentagonal, the median of hexagonal plates, as in *Melonites.* In the second row the seventh column is introduced by pentagon 7. It has an equal number of columns on either side, and has a heptagonal plate on its left ventral border. This heptagon is on the wrong side, as by the law of symmetrical development it should appear on the right border of pentagon 7; but such variations are quite frequent, as described under *Melonites.* In the fifth row above initial plate 7 the eighth column is introduced by pentagon 8, with a heptagon on its right. Column 8 has 3 columns on the left and 4 on the right, so that it is a left-handed series of plates, and also the heptagon is on the wrong side. In the sixth row above pentagon 8 the ninth and last column added is introduced by pentagon 9, with a heptagonal plate on its left. This plate by rule should be on the right of pentagon 9. This ninth column at its point of origin has 4 columns on the left and 4 on the right, its correct theoretical position.

At this horizontal plane and just above it there is one of the most irregular and unusual arrangements of plates seen in any Palæechinoid. Next to pentagon 9 on the left there is an accessory pentagon, *P*, which is a member of column 8, and to compensate for its missing side, as it should be a hexagon, there is a seventh side added to a plate, *H′*, next it on the left, which heptagonal plate is a member of column 5. The second plate, 9′, in the ninth column, is separated from the initial plate 9 by the interposition of 4 plates, 7′, 7′ and 8′, 8′, belonging to the two rows succeeding pentagon 9, and these 4 plates are respectively members of columns 7 and 8, as indicated by their numbers. One other case has been observed in which the initial plate of a column was separated from the second plate of its series, namely, that shown in the ninth column of *Melonites giganteus* (plate 5, figure 21), but in this case the succeeding plates of column 9 are only separated by the intercalation of one pair of plates, and the initial plate is tetragonal instead of pentagonal.* These are the only cases observed in the numerous specimens of Palæechini studied in which the successive plates of columns were not con-

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*Still a third case of the separation of successive plates in a column by the intercalation of the lateral plates of adjacent columns is shown in the specimen of *Oligoporus missouriensis* (plate 9, figure 50), and a fourth case is seen in *Rhoechinus gracilis*, in the seventh column of area *I* (plate 7, figure 36).

tinuous from their point of origin in the initial plate to the dorsal area, where the plates are normally separated dorso-ventrally by the stringing-out arrangement characteristic of newly formed plates, as shown in *Melonites* (plate 3, figure 13). This want of continuity in successive plates, as stated under *Melonites giganteus*, page 177, is to be explained by supposing that after the initial plate 9 was formed, no more plates were built in this column for a period in which two rows were added to the other columns of the area; then, in the third row, additions to column 9 were begun afresh. It is to be observed that this break of continuity in the cases described usually occurred at the point of introduction of a new column. No break at any other portion of a column has been observed in any Paleozoic Echini excepting *Rhoechinus gracilis*, as described on page 203.

When new columns are introduced, the initial plate is pentagonal; therefore after such a break of continuity as just described in *Oligoporus danæ* (plate 6, figure 31), the first plate, 9′, built after the break occurred should theoretically be pentagonal, as the mechanical requirements of the case are precisely the same as if it were a new column. It is seen, however, that plate 9′ is hexagonal; but an adjoining plate, *N*, of column 7 is pentagonal and bears a heptagonal plate, *H*, which is a member of column 6, on its right ventral border. This shows clearly that the pentagonal and adjacent heptagonal form may in the mechanical adjustment of growing parts be forced on to some other plates of the same row rather than be taken on by the actually new column introduced. If this very rare separation of the plates of the column had not taken place and initial pentagon 9 had not been formed, I should have described this case by saying that column 9 originated in plate *N*, with a heptagonal plate, *H*, on its right ventral border, the usual position; but the position of the column would be anomalous in having 5 columns on its left and 3 on its right. Just such a supposed condition may be the explanation of the position of the ninth column described in *Melonites multiporus* (catalogue numbers 3016 and 3023, tables, pages 165 and 168). This case of *Oligoporus danæ* is very instructive and suggestive, for it seems as if it might explain the apparently anomalous position of newly introduced columns in any of the cases of *Melonites* which are figured and tabulated, as in plate 9, figure 49. While with the addition of a new column the middle plate of a row commonly takes on a pentagonal form, which we therefore call the initial plate of the new column, this form may be shoved on some other plate of the same row, while the new column, which is probably still central, becomes continuous with the series of plates of a preceding column. To explain this idea in the case of *Oligoporus danæ* (plate 6, figure 31), column 9 as expressed by its upper limits, from plate 9′ upward, would be a direct continuation of column 7, without any means of distinguishing the fact that the resulting column was really made up by the combination of two separate columns.

The whole matter of columns requires critical consideration in this new light. Columns are the result of the superimposing of plates in successive rows. While columns are probably the clearest and easiest way of comparing the introduction and position of plates in an interambulacrum, the real feature of variation and progressive development is the row, the columns being the resultant of successive rows exposed in a limited area to lateral thrusts and pressure. Considering it in this light, at a certain period in the life of the genus, species and individual a row of one plate is built; this is the first row. In the next stage a row of two plates is built, then a row of 3, succeeded by 4, etcetera. When the higher numbers are attained, several rows of a given number of plates are built before the introduction of a row of a higher number of plates. When a row is built containing one plate more than the preceding row, some one plate by lateral thrusts is forced into a pentagonal form, which we naturally consider, therefore, the initial plate of a new series or column, as expressed in these pages. The plate which thus adopts the pentagonal form, as shown by tabulation of cases of odd-numbered columns in *Melonites* (page 163), is the median plate of the row in over 95 per cent out of 138 examples cited. The reason that this plate is dynamically selected is apparently because the middle plate of a row is that one which received equal pressure from both sides, and also being in the middle of an area built on a curved horizontal plane a newly added plate can there most easily effect an entrance to permanent position. When a row is built of one more plate than the preceding row possessed, we cannot probably say with positiveness which plate of the new row is the superadded one, although plates which are to form new columns are probably added in the middle of the area, as this conclusion is supported by such extremely definite arrangement in the method of addition of columns.

In the dorsal portion of the interambulacrum of this specimen of *Oligoporus danæ* (plate 6, figure 31) the form of the plates is gradually changed from the hexagonal outline of older plates to the characteristic rhombic form of young newly introduced plates, as described in *Melonites multiporus* (plate 3, figure 13). This change is effected as in *Melonites* by the gradual shorter and shorter length of the upper and lower sides of the hexagons. An entirely rhombic plate is not shown in this specimen; but such would doubtless have existed if the specimen had been preserved a little nearer to the dorsal termination of the area.

The spines of *Oligoporus danæ* have not been previously described. In a specimen of this species in Yale University Museum a number of spines are preserved. These spines (plate 6, figure 32) are long, cylindrical and swollen at the base. On some, faint longitudinal striæ were seen, which are apparently original ornamentation. The spines are longer than in *Melonites multiporus* (plate 2, figure 1), and do not show the bulging which is characteristic of that species. Probably the spines originally were longer than here figured, as they terminate distally in a blunt end which suggests a more elongate form when perfect. Another specimen of *Oligoporus danæ*, in Yale University Museum, shows an interesting condition of fossilization of ambulacral plates. This specimen (plate 6, figure 33) is silicified; but instead of the plates being silicified in parts of the test the spaces between the plates and the pores have been the seat of deposition of silica, as shown in plate 5. It is well known that silicification enlarges parts by accretion, so here we get a silicious ridge representing the space between plates which is much wider than the space between the plates themselves could have been, and the ambulacral pores which are represented by elevated plugs are larger than the pores in normal plates of the species. This specimen is of interest as throwing light on the structure of a specimen of *Rhoechinus gracilis* described in a succeeding chapter.

The ambulacrum of *Oligoporus danæ* (plate 6, figure 31) was described under the consideration of *Oligoporus coreyi* (page 190).

Turning to the excellent figure of *Oligoporus danæ* published by Meek and Worthen (30), the interambulacrum of which is reproduced in plate 6, figure 34, we find still further confirmation of the fact that the method of plate arrangement in *Oligoporus* is like that of *Melonites.* This figure of *Oligoporus*, it should be stated, is the only one previously published of any species in the family which at all adequately represents the method of plate arrangement and the introduction of new columns. Rather curiously the authors, while giving such an excellent figure, did not in their text make any mention of this arrangement; also, as published by them, this figure was inverted, with what we now know to be the ventral border uppermost. This is not at all strange, as the specimen did not show genital or ocular plates, which would have indicated the correct orientation, and deducting orientation from plate arrangement as here described was unknown. The figure as here published is modified from the original figure by omitting ambulacral plates, introducing letters, numbers and dotted lines to accentuate columns, and reversing the orientation in accordance with the new view.

Mr Jaggar, in his studies of the interambulacrum of *Melonites multiporus* (plate 3, figure 12) compared the plate arrangement in that specimen with that of this figure of *Oligoporus danæ;* therefore the comparison as described should be credited to him. This figure at the ventral border has a row representing 5 columns of plates, below which area it is not preserved; but the columns are numbered 1 to 5 to correspond with their usual relative positions. In the second row a new column is introduced by the pentagon 6. Column 6 at its origin has 2 columns on the left and 3 on the right, as in *Melonites multiporus* (plate 2, figure 2, area *G*). It is therefore a left-handed series. The seventh column starts in the third row above pentagon 6 in pentagon 7, which has a heptagonal plate, *H*, on its right border. Column 7 at its point of origin has an equal number of columns on either side, as usual. In the fourth row above pentagon 7 the eighth column originates in pentagon 8, with a heptagon, *H*, on its left. This column at its origin has 4 columns on the left and 3 on the right. The ninth and last column originates in pentagon 9 in the eighth row above pentagon 8. Pentagon 9 has a heptagonal plate, *H*, on its right border and has 4 columns on either side. This last ninth series completes the number of columns, no more than 9 being known in the species.

Comparing these two specimens of *Oligoporus danæ* (plate 6, figures 31 and 34), it is seen that the method of plate arrangement and introduction is exactly the same as that traced in the genus *Melonites*. The similarity is in the terminal pentagons with adjacent heptagons, the number of columns on the left and right of newly introduced columns, and the passage of plates dorsally into the rhombic form characteristic of newly introduced plates. Meek and Worthen's figure corresponds to the ideal method of plate arrangement, except in having column 6 one row too far to the left. The other specimen shows no more variations than are just what might be met with in *Melonites multiporus*.

Oligoporus nobilis, Meek and Worthen (31), as figured by the authors, does not show indications of the method of introduction of plates, but in the text we find the statement that the interambulacra are " . . . composed of five rows [columns] of large plates, all of which extend to the disc above, while the middle one ends [begins] within about 0.65 inch of the oral opening below." This was evidently correctly oriented by Meek and Worthen, as the genital plates are described. Therefore this species as *Oligoporus danæ* increased the number of columns as it grew dorsally. Its fifth column is acquired very early, but not earlier than in *Melonites giganteus* (plate 5, figure 21), where it begins close to the oral area. This species, *Oligoporus nobilis*, in the whole length of the figure published, does not show the addition of any new columns, which would have been figured, I am confident, had they existed, as Meek's drawings of Palæechini are among the most accurate met with. This length is a distance represented by the introduction of 21 rows of plates and is a greater number of rows built without additional intercalated columns of any species of Palæechini seen. Spine bosses of *Oligoporus nobilis* are shown in plate 6, figure 35.

The above described specimens of the genus *Oligoporus*, while not numerous in individuals observed, are sufficient to make a fair relative comparison with the genus *Melonites.* The relations of the ambulacra have already been described in the two genera under the consideration of *Oligoporus coreyi* (page 191). The ambulacra of *Oligoporus* begin ventrally as 2 columns of plates, and proceeding dorsally these 2 become 4 by the pulling apart of one row on each side to make 2. *Melonites* has 4 columns of ambulacra at the ventral border, like adult *Oligoporus*, and these increase by the addition of new columns during progressive growth of the individual to 10 columns in *Melonites multiporus*, Norwood and Owen; 12 in *M. giganteus*, Jackson and 12, or 14, in *M. etheridgii*, Keeping (21). There are 4 columns of ambulacra in *Oligoporus* in all the species. In the feature of ambulacral areas *Oligoporus* is therefore distinctly more primitive in the scale of organization than *Melonites.* In the interambulacra there is a progressive development in both genera from two columns represented by two plates at the ventral border to many columns in the adult. Therefore those species with few columns are obviously more primitive in organization in this respect than species with many columns. The number of columns in the interambulacra of *Oligoporus* varies from 4, as described in *O. bellulus*, Miller and Gurley (34), and 5 in *O. nobilis*, M. and W., to 6 in *O. blairi*, Miller and Gurley (34), and *O coreyi*, M. and W., and finally 9 in *O. danæ*, M. and W. In *Melonites* the columns of interambulacra vary in species from 4 in *M. dispar*, (Fischer) (12) to 5 in *M. crassus*, Hambach (18), to 6 in *M. indianensis*, Miller and Gurley (34); 7 in *M. septenarius*, Whitfield; 7 to 8 or 9 in *M. multiporus*, Norwood and Owen, and finally 11 in *M. giganteus*, Jackson. Species of *Oligoporus*, then, have from 4 to 9 columns of interambulacra, and species of *Melonites* have from 4 to 11 columns. Therefore the sum of the species of *Oligoporus*, as compared with the sum of the species of *Melonites*, shows that in regard to the interambulacra, as well as the ambulacra, *Oligoporus* is more primitive as a genus than *Melonites.*

Both *Oligoporus* and *Melonites* in their development progressively increase from 2 and doubtless earlier from 1 interambulacral plate in the young to many columns in the adult, which indicates a common ancestor with one and intermediate common ancestors with few columns in the adult. Accepting this, *Melonites* should be considered a further remove from the primitive than *Oligoporus*, because its species acquire more columns of plates. Species with few columns of plates may be considered more primitive, other things being equal, because they represent in the adult condition, stages passed through in their development by those species having a larger number of columns in the adult.

It seems that *Melonites* may be considered the extreme genus of the

Melonitidæ, because the species as a whole and some individually are farthest removed from the primitive in the direct line of variation of the group. It may also be considered the most extreme known form of Palæechini in the line of plate multiplication, having in both ambulacra and interambulacra more columns of plates than any other genus.*

The systematic intercalation of new columns during growth necessarily renders the number of columns a somewhat unsafe specific character where the description is based on imperfect materials, for a more complete specimen might show that higher up more than the supposed number of columns existed; also, as new columns were added during the development of the individual and mark stages in growth, the number of columns is a criterion not of specific differentiation only, but of age as well † (see page 188).

CONSIDERATION OF *RHOECHINUS* AND *PALÆECHINUS*.

NOTES ON EARLIER STUDIES.

The genus *Rhoechinus* was founded by W. Keeping (22) for a single species, *R. irregularis*, W. Keeping. Dr Duncan (8) in a critical study of ambulacral areas of *Palæechinus* divided that genus. He transferred to the genus *Rhoechinus* those species which have but one vertical row of pores in each half ambulacrum, as *R.* (*Palæechinus*) *gracilis* (plate 7, figure 37) and *R.* (*Palæechinus*) *elegans* (plate 7, figure 40). In the older genus, *Palæechinus* pars, M'Coy, he retained those species which have a double vertical row of pairs of pores in each half ambulacrum, as in *Palæechinus gigas* (plate 7, figure 39).‡

This division of the genus *Palæechinus* is most satisfactory and is in accordance with the relations expressed in the progressive development of ambulacral plates in the Melonitidæ (figure 1, page 191). While Dr Duncan considers this difference of the two genera, he does not state the fact that on account of this difference *Rhoechinus* is more simple in its structure and *Palæechinus* is more specialized, having made first steps in the line of increase of ambulacral columns of plates.

I cannot agree with Dr Duncan (9) in putting *Rhoechinus* and *Palæechinus* in the family Archæocidaridæ. The fact of two columns of ambulacral plates in each area seems insufficient evidence for such grouping

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* In one species, *Lepidesthes colleti* White (41), this number of ambulacral plates is exceeded, for this species has eighteen, and perhaps twenty, columns of ambulacral plates according to White.

† This is opposed to Messrs Miller and Gurley's view. See page 138.

‡ I would state that I had independently arrived at the same conclusion in regard to the ambulacral plates in M'Coy's old genus *Palæechinus* as Dr Duncan. In fact, the manuscript was written for the succeeding sections, describing *Rhoechinus* and *Palæechinus*, and all accompanying figures were drawn before seeing his paper. Practically the only changes introduced are the substitution of *Rhoechinus* for *Palæechinus* where that name applies.

when the sum of the characters of both genera link them closely with *Oligoporus* and *Melonites* as members of the Melonitidæ. The whole development and structural details of the several genera bear out this conclusion and as distinctly remove them from the Archæocidaridæ. In his paper Dr Duncan (8) gives a list of the species to be included in *Rhoechinus* and *Palæechinus*, which list has been followed for these genera in the systematic classification of Paleozoic Echini (table facing page 242).

STRUCTURE AND PLATE ARRANGEMENT OF RHOECHINUS GRACILIS.

The species *Rhoechinus gracilis*, (M. and W.), Duncan, as described by the authors (31), was from the Burlington limestone of Burlington, Iowa. The type specimen consisted of portions of two interambulacral and an included ambulacral area. It was incomplete dorsally and ventrally, and the figure was incorrectly oriented, as ascertained by the position of the terminal pentagonal plate of column 7 and its adjacent heptagon. In the Student Geological Collection of Harvard University there are two specimens of *Rhoechinus gracilis* which are very well preserved. The specimens (catalogue number 115) are in a single small slab of sandstone from the Waverly group, collected by A. R. Crandall, on Beaver creek, one mile above the mouth of Leatherwood creek, Menifer county, Kentucky. Though the specimens are from a formation just below the Burlington group, where the original material was collected, I see no evidence in the fossils for ascribing them to another species. The specimen figured (plate 7, figure 36) is a sandstone cast of the exterior of the test, but viewed from the interior. The original curved form of the test is retained in considerable degree, so that the genital ring is in the center of a quite deep depression in the rock. The lettering of areas is reversed from what it would be if the specimen were viewed from the outside, but this makes little confusion in studying the specimen.

The original specimen of the species showed but 7 columns of interambulacral plates, but it was fragmentary, and would probably have shown the addition of one more column had it been perfect at the dorsal area. In the specimen here figured in all the interambulacral areas there are 8 columns of plates, and one of the areas exceeds that number, attaining 9 columns. Interambulacrum *A* is the most perfect one. On its ventral border, as far as preserved, it has a row of 5 plates, indicating but 5 columns at this level. In the next row from the base a sixth column is introduced by the terminal pentagon 6. This column at its origin has 2 columns on the left and 3 on the right, which, when reversed, as it must be for comparison with the outside, is seen to be the usual position for this column. In the second row above pentagon 6, column 7 is introduced by the pentagon number 7, with an equal number of columns on either side and a heptagonal plate on the left (right as viewed from without). Six rows above pentagon 7 the eighth column is introduced by pentagon 8, with a heptagonal plate on its right. Column 8 has 3 columns on the left and 4 on the right, these and the heptagonal plate being in the correct position when reversed for viewing from the outside.

Ambulacrum *B*, as the other ambulacral areas, has crenulations on the sides of the area and a median crenulation corresponding to the outer and median borders of two columns of low ambulacral plates. On account of the small size of the ambulacral plates and the relative coarseness of the sandstone cast, the outlines of the plates cannot be further determined, but they are indicated by restoration in the dotted lines connecting the crenulations in ambulacrum *J*. On account of the condition of preservation, I could not say whether or not the plates of each half ambulacrum lapped over one another. Meek and Worthen's figure of the species, however, cited above and here copied in plate 7, figure 37, shows the ambulacral plates slightly overlapping, much as in *Rhoechinus elegans* (plate 7, figure 40). Interambulacrum *C* at the lower border, as far as preserved, has 7 plates, representing 7 columns. The eighth column is introduced by pentagon 8, with a heptagonal plate on its right. Column 8 at its origin has 3 columns on the left and 4 on the right. This relation and the position of the heptagon are normal when reversed for comparison with an outside view of the area. Area *C* has a ninth column introduced by pentagon 9, with a heptagon on the left (right as viewed from without) and 4 columns on either side. This ninth column is probably to be considered an exceptional addition. No species of *Rhoechinus* has previously been described as having 9 columns. In interambulacrum *E* there is a row of 7 plates on the ventral border as far as preserved. The eighth column is introduced by pentagon 8, with 4 columns on the left and 3 on the right (the incorrect position when reversed for comparison with the outside). Next to pentagon 8, on the left, is an octagonal plate, *O*, corresponding to a heptagonal plate (and in the incorrect position when reversed for comparison with the outside). A heptagonal plate exists at *O'*, and two tetragonal plates at *T T'*; also a heptagonal plate exists at *H*. The angles of these plates compensate in part for the want of one side in pentagon 8 and the want of two sides in tetragons *T* and *T'*. A similar compensation of sides is seen around pentagon 9 in *Melonites giganteus* (plate 5, figure 21). Interambulacrum *G* has a row of 7 plates on the ventral border as far as preserved. The eighth column is introduced by pentagon 8 with a heptagon on its right and with 3 columns on the left and 4 on the right, the normal position when reversed for comparison with the outside. Interambulacrum *I* is similar to *G*, except that column 8 and its adjacent heptagon are one column too far to the left when reversed for comparison with the outside The seventh column of area *I* near the dorsal border is discontinuous in one row where two plates, *H H*, of columns 5 and 8 come in contact. The plates of column 7 are modified into pentagons of alternately opposite position above and below the two heptagons. No other case of a break just like this has been seen (see page 194).

At the dorsal border the outlines of 5 genital and 2 ocular plates are more or less visible. The genitals are large and similar to the genitals of *Palæechinus*, as figured by Bailey (5). Pores exist in these plates of *Rhoechinus gracilis*, but they are too irregular and poorly preserved to have value attached to their number. The oculars are not well differentiated. They apparently reach to the periproct. The plates of the interambulacra in the dorsal portion assume a more or less rhombic form, as described in *Melonites* (plate 3, figure 13), and *Oligoporus*, so that here again this is the character of newly added plates.

The outlines of plates in the cast are represented by comparatively thick ridges, corresponding to the spaces between the plates. The ridges are thicker than the spaces between the plates could have been, and this is ascribed to enlargement from semiferruginous accumulation, just as in *Oligoporus danæ* (plate 6, figure 33) a similar enlargement is caused by silicification. Each of the interambulacral plates has a number of papillose projections, evidently corresponding to the position of spine bosses, as shown in interambulacrum *I*. As the specimen is a cast of the outside, spine bosses should be depressions, not elevations. The reason of the elevation of these areas is not understood. The spine tubercles of *Rhoechinus*, as other members of the *Melonitidæ*, are imperforate, not perforated, as in *Cidaris*, etcetera. These elevations therefore cannot be considered as enlarged casts of the pores of tubercles, as has been suggested. The width of |the ambulacra at the widest part is 5 millimeters, that of the interambulacra at the same horizon is 14 millimeters.

We have, then, in *Rhoechinus* the same method of arrangement of plates and introduction of columns as has been previously described in *Melonites* and *Oligoporus*.

NOTES ON RHOECHINUS BURLINGTONENSIS.

Only two species of *Rhoechinus* have been described from American formations—one, *R. gracilis*, which has just been considered, and another, *Rhoechinus burlingtonensis*, (Meek and Worthen) (30). Both species were described under the genus *Palæechinus*. This latter species is from the Burlington limestone, Burlington, Iowa. The species was described by the authors from a specimen which showed the median portion of 3 interambulacral and 2 ambulacral areas. It was incomplete dorsally and ventrally, and the published figure was incorrectly oriented, as ascertained by the introduction of the fourth column in the middle interambulacrum. The type is in the Worthen collection at the University of Illinois, at Urbana, Illinois (see foot-note, page 136). As figured it showed but 4 columns of interambulacral plates, being only a portion of a test, but, as the authors say, it would very probably have had more columns if more completely preserved. In the Museum of Comparative Zoölogy there is a specimen of *Rhoechinus burlingtonensis* (catalogue number 3009) from the same horizon and locality as the type. Besides other portions of the test, this specimen has one interambulacrum nearly entire, and this area in the upper portion has 6 columns of plates, showing that Meek and Worthen were correct in supposing that the species might have more than 4 columns of plates.

The plates of the ambulacrum of the Cambridge specimen consist of two columns, each of which is continuous across its own half area, as shown by Meek and Worthen's figure. The species therefore distinctly belongs to the genus *Rhoechinus*, as emended by Duncan (8).

OBSERVATIONS ON PALÆECHINUS GIGAS AND RHOECHINUS ELEGANS.

No species of the true genus *Palæechinus* as emended by Dr Duncan has so far been discovered in America.

Mr T. A. Jaggar recently saw in London, at the Geological Museum in Jermyn street, a specimen of *Palæechinus gigas*, M'Coy. By the kindness of Dr E. T. Newton he had an opportunity to study the specimen, which is from the Carboniferous of Clitheroe, Lancashire. On plate 7, figures 38 and 39, are reproductions of Mr Jaggar's drawings, for which I am indebted to him.

The interambulacrum of this species is described as having 6 columns of plates, and such are shown in M'Coy's (28) original figure, which does not, however, show the method of introduction of new columns. At the ventral border of this specimen (plate 7, figure 38) we see the initial beginning of the fifth column in pentagon 5. Plates below this area are not preserved, but they would evidently below pentagon 5 consist of a row of 4 plates, which would be members of columns 1, 3, 4 and 2 (the last column, 2, in the figure is a restoration, as indicated by dotted lines). In the second row above pentagon 5, the sixth column is introduced by pentagon 6, with a heptagonal plate, *H*, on its left ventral border. The position of columns 5 and 6 and the position of the heptagonal plate are normal, according to the ideal method of arrangement as worked out for *Melonites*. After the sixth no more columns are introduced in this species. It is to be observed that these 6 columns were introduced relatively very early in the life of the individual, so that when quite young it had attained the maximum number of interambulacral columns, and during later growth only new rows were added to the columns already existent. A similar condition of early attaining the full number of columns exists in *Oligoporus nobilis*, as figured by Meek and Worthen (31), and an approach to this condition is seen in *Oligoporus coreyi* (plate 6, figure 28). Most Palæechini, on the contrary, are less accelerated in their development and do not attain the full number of columns until much later in life, as shown in this paper in *Melonites*, *Oligoporus danæ*, *Pholidocidarus*, *Lepidechinus* and other genera.

The ambulacral area of *Palæechinus gigas* (plate 7, figure 39) is interesting for comparison with other species of its genus and also with the genus *Oligoporus*. M'Coy's (28) figures of the ambulacrum of this species show 4 pores in each plate, which is evidently an error. In each half ambulacrum the plates are drawn out so that none of the plates cross the area; they must therefore be considered as 2 columns of plates *b* and *b'*, each plate having 2 ambulacral pores.

In *Rhoechinus elegans*, M'Coy we find a different type of ambulacrum from *Palæechinus*, and this type may be taken as representative of the genus. In a specimen of *Rhoechinus elegans* from the Carboniferous of Hook Head, Ireland, in the Museum of Comparative Zoölogy (catalogue number 3002) an ambulacral area is clearly shown (plate 7, figure 40). In this it is seen that while alternate ambulacral plates overlap one another slightly or occasionally entirely on the outer border, yet each plate, or practically each plate, may be said to extend quite across its own half ambulacral area. It may be considered as representing the first step in the change from a form of plate which extends entirely across its half area unmodified, as in *Bothriocidaris* (figure 4, page 234), *Archæocidaris* and *Cidaris* (plate 8, figures 43, 48), to that condition where each plate extends only part way across its area, as in *Palæechinus gigas* (plate 7, figure 39). This is an important consideration in view of the changes I have traced in the development of *Oligoporus* (plate 6, figure 25), where ventrally the plates extend quite across the area, and succeeding plates as introduced gradually fall short of this relative length in an increasing degree until the length of each plate is only half the total width of the half ambulacrum in which it is situated (plate 6, figure 30). The anatomical and morphological relations of the ambulacral plates in these several genera is diagrammatically shown in figure 1, page 191, to which attention is especially called. In this diagram and the accompanying plates we see that columns *a b* of *Rhoechinus elegans* are the equivalent of columns $a+a'$ and $b+b'$ of *Palæechinus gigas*, and consequently columns *a b* of *Rhoechinus* are the morphological equivalents of columns *a b* at the base and $a+a'$ and $b+b'$ at the upper portion of *Oligoporus coreyi* (plate

6, figure 25); they are also the equivalents of $a+a'$ and $b+b'$ in *Oligoporus danæ* (plate 6, figure 30) and *Melonites multiporus* (plate 2, figure 4, and plate 5, figure 20).

The interambulacral plates of *Rhoechinus elegans* have their edges inclined slightly outward, and the adambulacral plates extend under the sides of the adjacent ambulacrals, as in *Melonites* (plate 2, figure 5) and *Oligoporus.* This feature is doubtless characteristic of the family, as it is existent in these representative genera.

The method of plate arrangement and introduction in the interambulacrum of *Palæechinus* as shown above is seen to conform to the laws of growth that have already been demonstrated in *Melonites* and *Oligoporus* in the earlier part of this and the preceding paper.

STUDIES OF THE LEPIDESTHIDÆ, FAM. NOV.

RELATIONSHIPS AND CHARACTERISTICS.

The family Lepidocentridæ is composed of genera associated as nearest allies with the family Archæocidaridæ, but separated by strongly imbricating plates and other features. In the genera *Lepidesthes* and *Pholidocidaris* we have another group of types also characterized by imbricating plates. The species of these genera all have 6 or more columns of ambulacral plates in each area, and this feature allies them with the Melonitidæ. In fact, they have always been included in this family. These genera, however, have characters which distinguish them as a group by themselves, and a separate family is therefore founded for their reception.

The Lepidesthidæ, fam. nov., is named from *Lepidesthes*, which genus is the least aberrant and is represented by the largest number of species of either included genus. The family is characterized (see systematic classification facing page 242) by having from 6 to 10, and in one species 18 or perhaps 20, columns of ambulacral plates in each area. The interambulacral areas of the 2 genera and several species have from 3 to 6 columns of plates, though this number is likely to be increased by more perfect specimens or perhaps new species. The peristome is small with no interambulacral plates resorbed, as known in *Pholidocidaris* (figure 54, plate 9) from observation, and known in *Lepidesthes* from Meek and Worthen's description of *L. coreyi.** One unusual feature is characteristic of the genera of this family, that the pores occupy a position in the center

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*This character is peculiar to several aberrant groups of Echini (as discussed later on page 237), being a feature of the Lepidocentridæ (*Lepidechinus*, plate 7, figure 42) and the Exocyclica as well as the present family. It is characteristic of the young of all Echini, and therefore is to be considered a primitive character and probably retrogressive in aberrant types.

of the ambulacral plates instead of being in the outer portion of the plates as in most Paleozoic Echini.

Two genera are included at present in this family, *Lepidesthes*, which is the least specialized in the peculiar line of variation of the family, and therefore is to be considered the most primitive. *Hyboechinus* was described as a separate genus by Worthen and Miller (42), but from meager and somewhat doubtful material. The single known species, *H. spectabilis*, is included in the genus *Lepidesthes* by Keyes in his Synopsis (24), and under the circumstances we would prefer to leave it there. The type of *Hyboechinus spectabilis* is in the Illinois State Museum at Springfield, Illinois.* The second certain genus of this family is *Pholidocidaris*, which is the more aberrant genus on account of the irregularity of its ambulacral and interambulacral plates.

DESCRIPTION OF LEPIDESTHES WORTHENI, SP. NOV.

Plate 9, figure 53.

This species, which is named for Professor A. H. Worthen in consideration of his work on American Paleozoic Echini, is represented by a single specimen in the Boston Society of Natural History, catalogue number 11601, and I am indebted to the kind interest of Miss I. L. Johnson, who called my attention to it. The specimen has the original calcareous plates, and as known from associated fossils (*Platycrinus hemisphericus*, M. and W. and *Scaphiocrinus depressus*, M. and W.) is from the Keokuk group of the Subcarboniferous. The locality is not known, but the fossils were in a blue or grayish and gritty clay, which corresponds with the fine and occasional coarser matrix of material from Crawfordsville, Indiana. The specimen is probably from this or a neighboring locality.

The specimen, plate 9, figure 53, is flattened by crushing. On the opposite side from that figured dental pyramids are shown at the oral end, and these serve to orient the axes. The height is 3.6 centimeters; width, 2.7 centimeters. The ambulacra at the ambitus measure 0.9 of a centimeter in width; the interambulacra measure from 0.5 to 0.6 of a centimeter in width. The clearest ambulacral area, *B*, is shown in the figure, plate 9, figure 53. There are seven to eight columns of ambulacral plates. Eight may be counted at the ambitus in one horizontal plane. The plates are subhexagonal in outline, or near the dorsal area, nearly or quite tetragonal. They are very regular in form and arrangement, and each plate is perforated by two pores situated in the middle of the plate. At the ventral border of the ambulacrum only four columns of plates exist, as shown by the figure in area *B*. These plates differ from those in

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*As I am informed by Mr Wm. F. E. Gurley, state geologist of Illinois.

the upper portion of the test in being distinctly hexagonal instead of subhexagonal or tetragonal in form; they also differ in being more drawn out in the horizontal axis. The plates of this ventral portion of *Lepidesthes* are closely like the plates of the ventral border of *Melonites multiporus*, plate 2, figure 3, the similarity being in the number of columns and the outline of the individual plates. This is a very important fact in view of the systematic relations of the genera. The passage from the four columns at the base to the eight columns seen higher up is hidden by local imperfections of the specimen. There are about two plates opposite each interambulacral plate.

The clearest interambulacrum, which is area *A* of our figure, consists of three columns of plates at the ambitus and throughout the greater part of its length. At the ventral portion, however, a fourth column exists. In area *C* the fourth column is clearly defined and terminates dorsally in a plate *A*, above which it could not be traced. This fourth column exists for such a brief period it seems reasonable to say that three columns is the preponderant feature of the species. It is an unusual feature not seen in any other species of Palæozoic Echini for the greatest number of interambulacral columns to exist so close to the ventral border and then one to drop out (see page 150). It might be questioned whether this is the ventral end except for the presence of buccal pyramids which are clearly seen on the other side of the specimen and are just visible as two projecting points, *D D*, on the side which is figured. The structure of ambulacrum *B* also serves to orient the axes. The two outer columns of interambulacral plates are nearly or quite hexagonal, not pentagonal as in *Melonites*; the plates of the median column are also hexagonal. Most of the plates are worn so that they do not show surface ornamentation; but at the ventral portion of interambulacrum *C* the plates are marked by somewhat obscure and very slight spine bosses, all of one kind and scattered evenly over the surface of the plates. The interambulacral plates imbricate aborally, while the ambulacral plates imbricate also, but adorally.

A specimen in Yale University Museum evidently belongs to this species. It is from the Keokuk group, of Crawfordsville, Indiana. It is of the same size and proportions as the type, and is densely clothed with small spines about 2 millimeters in length. Jaws are well preserved at the oral pole. Another specimen in Yale University Museum, also from Crawfordsville, as ascribed to this species, *Lepidesthes wortheni*. It is considerably smaller than the type, measuring only 1.3 centimeters in height, so that it is probably a young one. The ambulacral plates, both ventrally and at the ambitus, are similar to those shown in plate 9, figure 53, but only seven columns were made out. In the interambulacra there are three columns of plates. Four columns are not visible ventrally as in the type. This differential character may be sufficient to base specific difference on, but with present knowledge I should consider the specimen as *Lepidesthes wortheni.*

Lepidesthes wortheni in the form of the plates and the configuration of the fossil approaches nearest to *Lepidesthes formosus*, Miller (33), but differs from it in having fewer columns of interambulacral plates. It differs from other species of the genus in having fewer columns of both ambulacral and interambulacral plates.

NOTES ON OTHER SPECIES OF LEPIDESTHES.

The genus *Lepidesthes*, Meek and Worthen, is an interesting member of the Lepidesthidæ on account of being represented by the largest number of species of any genus in the family and being therefore the best known. Meek and Worthen (31) give a good figure of *Lepidesthes coreyi*, M. and W., which is from the Keokuk group of Crawfordsville, Indiana. This species, which is the type of the genus, is characterized by 10 columns of ambulacral plates which are sub-hexagonal and imbricating. The plates of the interambulacrum are pentagonal in the adambulacral columns, otherwise hexagonal. Meek and Worthen say of it that there are, near the middle, 6 or 7 (rows) columns of plates, decreasing toward the extremities, first to 5, then to 4, and so on to the ends, where each seems to terminate in a single piece. The species was founded on a single specimen in which the oral pole only existed; therefore from their statement we would gather the conclusion that the interambulacra originated ventrally in a single plate, like *Pholidocidaris* in this family (plate 9, figure 54) and *Lepidechinus* (plate 7, figure 42) of the Lepidocentridæ, and as the Echinus grew dorsally by addition of new rows of plates additional columns were progressively added until 6 or 7 were attained at the ambitus.

Studying Meek and Worthen's excellent figure of *Lepidesthes coreyi*,* we find that the interambulacrum at its ventral border, as far as shown, has 4 columns of plates. A fifth column is introduced in the ninth row from the bottom of the figure by a pentagonal plate, with a heptagonal plate on its left. This column at its point of origin has 3 columns on the left and one on the right. This is an irregular position for the fifth column, as odd-numbered columns characteristically originate in a median position, with an equal number of columns on either side; also the heptagonal plate adjoining the terminal pentagon of odd columns ordinarily occurs on the right. These variations, however, are just what are occasionally met with in *Melonites*, and for comparison attention is directed

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*Geol. Survey of Illinois, vol. v, plate xvi, figure 2.

to the tabulations of *Melonites multiporus* (catalogue numbers 2992 and 3004, on page 170 of the preceding paper). In *Lepidesthes coreyi* after the fifth, a sixth column is introduced in the seventh row by a pentagon, with an octagonal plate on its right ventral border. Column 6 originates with 2 columns on its left and three on its right, and is therefore one column too far to the left according to the rule of ideal arrangement. The fact of an octagonal plate next a terminal pentagon is abnormal, but there is considerable irregularity in the plates at this area, as the plate below the octagon which might have 6 sides has 7 and a plate to the left of this heptagon is pentagonal, although not a terminal plate of a column.

Lepidesthes formosus, Miller, is represented by the author of the species (33) by an especially good figure. which adds to the knowledge of generic features by showing genital and ocular plates, both of which are perforated. Miller describes the ambulacral plates as imbricating downward, while the interambulacral imbricate upward and outward. Both this species and *Lepidesthes coreyi* also have the pores situated in the middle rather than the outer side of the ambulacral plates. The published figure of *Lepidesthes formosus* does not show the introduction of any new columns of plates, the full number, 5, extending as far ventrally as the specimen is preserved.

Lepidesthes colletti, White, is a remarkable species, having, according to its author (41), 18 or perhaps 20 rows [columns] of ambulacral plates. This is a most unusual number, no other echinoid known having more than 12 or 14 columns of ambulacral plates, which number is ascribed to *Melonites etheridgii*, W. Keeping (21). *Lepidesthes colletti* in this feature, then, is the most highly specialized species of all Echini. The interambulacra, however, do not show any extravagant development, there being only 4 or 5 columns, as described. The types of *Lepidesthes formosus* and *colletti* are in the private collection of Mr Wm. F. E. Gurley, of Springfield, Illinois.

The plate arrangement of interambulacral plates of *Lepidesthes*, then, as gathered from the description and figure of *Lepidesthes coreyi*, agrees with that of *Melonites*, *Oligoporus* and *Palæechinus*, having only such variations as have been already met with in *Melonites*.

DESCRIPTION OF *PHOLIDOCIDARIS MEEKI*, SP. NOV.

Plate 9, figure 54.

The genus *Pholidocidaris*, Meek and Worthen was instituted by the authors for a single species *P. irregularis*, M. and W. (31). The type of this species is in Illinois State Museum at Springfield, Illinois (see footnote, page 207). The material as described and figured was limited and wanting in some essential characters. It is with satisfaction, therefore, that I have the opportunity to describe a new species which adds to the known features of the genus.

Pholidocidaris meeki, sp. nov., is from the Keokuk group, Subcarboniferous, of Warsaw, Illinois. The single specimen of the species is in the collections of the Museum of Comparative Zoölogy (catalogue number 3070). This species is dedicated to the late Mr F. B. Meek in recognition of his important labors on the Paleozoic Echini. The publications of Messrs Meek and Worthen on this group are by far the best and most extensive done in America and are equal to the very best of European works.

The specimen of *Pholidocidaris meeki* is in a limestone matrix and preserves the original form and structure of the plates with little alteration save local distortions due to fracturing. The specimen is preserved ventrally to the oral orifice in parts of the test, but is incomplete dorsally. The accompanying figure, which is life size, shows the measurements of the several parts.

The plates of this species, both ambulacral and interambulacral, are thin, scale-like, very irregular in form, and in both areas imbricate adorally. On account of the thinness and strong imbrication of the plates the test must have been very flexible, more so than any other Paleozoic Echini studied, unless perhaps *Lepidocentrus eifelianus*, Müller, which has similar thin, strongly imbricating plates. These species in the flexibility of the corona must have borne a close resemblance to the modern genus *Asthenosoma.*

In the ambulacrum 6 columns of plates are certainly existent, and perhaps 7, but on account of local distortions this higher number is somewhat uncertain. Ventrally at the border of the peristome the number of columns of ambulacral plates is reduced to few, apparently 4, as in *Lepidesthes*, but the exact number was not ascertained on account of local imperfections. The plates of the ambulacra are quite large, very irregular in outline, and in the center of each plate is a raised mammillate boss surrounded by a depressed areola. On the sides of the boss and associated with the areola are two quite large pores in each plate. A remarkable feature of these pores is the fact that while some are arranged in a horizontal plane as compared with the test as a whole, many are arranged in an inclined or even vertical plane. Thus the angles of pore pairs are very various in different plates of the corona. The same condition of irregular arrangement of pores may have existed in *Pholidocidaris irregularis;* but the ambulacral plates in Meek and Worthen's figure (31) are so dissociated that the fact, if so, could not be there ascertained. This irregularity is quite unlike anything which I have seen in other echinoderms. Its nearest analogy perhaps is seen in *Cidaris* (plate 8, figure 48), where the pore pairs in the peristome are arranged vertically, while the pore pairs of the corona are horizontal in position. Jaekel (20) states that the pores in *Bothriocidaris* are arranged vertically in all coronal ambulacral plates, though this observation is contrary to Schmidt's (37) (see our figure 4, page 234). In the ventral portion of the specimen of *Pholidocidaris* are small ovally rounded ambulacral plates which are dissociated, but apparently belong to the peristome. No spine tubercles were observed on any ambulacral plates, but their absence is probably due to the weathering of the surface.*

The interambulacrum of *Pholidocidaris meeki* (plate 9, figure 54) originates ventrally in a single pentagonal plate, 1′, like *Lepidechinus* (plate 7, figure 42), *Goniocidaris* (figure 3, page 234), *Strongylocentrotus* (plate 3, figure 8), and other genera. That this first plate is the ventral border of the corona we know from the presence of a certain number of buccal pyramids, *D*, in place and closely related to the corona. In the second row there are two plates, 1 and 2, which lead up by additions to the two columns of adambulacrals,† as shown in many other genera in this paper. The third, fourth, fifth and sixth columns of interambulacral plates are introduced in succession, as indicated by the numbers and dotted lines, much as in *Melonites* (plate 2, figure 2), allowing, however, for the differences in their regular imbricating plates of *Pholidocidaris*.

Comparing the interambulacrum of *Pholidocidaris* (plate 9, figure 54) with that of *Lepidocentrus* (figure 2, page 223) and *Lepidechinus* (plate 7, figure 42) one striking feature is noticeable, namely, that these two last mentioned genera have a very accelerated development, the columns of plates being introduced much more rapidly than in *Pholidocidaris*. It is also noticed that the form of individual plates, while irregular in outline in all three genera, is also different in the three genera.

The interambulacral plates of *Pholidocidaris irregularis* as figured, have relatively large primary spine bosses, but these are situated irregularly and not in the center of the plates, as is usual in primary tubercles. In addition to these larger bosses, numerous small bosses are scattered thickly over the surface of the plates. In the present species, *P. meeki*, the surfaces of the plates are too much worn to show any spine tubercles, except a few of the primary size (none are shown in the figure). These are similar in position to those in *P. irregularis*, and probably the spine tubercles of both species are alike. The spines are tapering, acicular, termi-

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* On account of imperfections of the specimen, to avoid confusion only the clearest portions are shown in plate 9, figure 54. Some of the details described do not appear in the figure.

† Column 2 is wanting for a space above the second plate of its series, but the place where absent plates should exist is indicated by the dotted line. A misplaced ambulacral plate, *A*, lies in this line where interambulacra should be.

nating somewhat bluntly distally (probably from erosion) and proximally enlarged, as usual in echinoid spines.

The oral region of the specimen of *Pholidocidaris meeki* is difficult to make out, being considerably crushed and the parts not being sharply differentiated. Buccal pyramids are to be made out in two areas, one of which is shown in the figure. The pyramids are in two halves, united by a median suture, as in *Archæocidaris* (plate 8, figure 43), *Melonites* and modern Echini. They lie opposite the interambulacral areas, their correct position. The teeth. which should occur at the oral apex at the confluence of each pair of pyramids, are not preserved. Actual teeth have not been described, so far as I am aware, in any Paleozoic Echini, though the pyramids are known in several types. A very perfectly preserved specimen of an Aristotles lantern in Yale University Museum shows the pyramids with teeth in place in their usual position. This specimen, which at present is not generically placed, is from the Keokuk group, Subcarboniferous, of Crawfordsville, Indiana.

Pholidocidaris meeki differs from the only other known species of the genus *P. irregularis*, in having more definite form to the interambulacral plates, they being more rounded and almost biscuit-shaped; also larger in the latter species. In *P. meeki* no very small ambulacral plates were seen in the corona, such as are figured in *P. irregularis.* The spines of both species are much alike in size and shape.

Meek and Worthen (31) expressed considerable doubt as to the affinities of *Pholidocidaris;* but, with this fuller knowledge of the genus, we can have no hesitation in including it in the *Lepidesthidæ* as an aberrant genus. It has many features linking it with *Lepidesthes*, and yet not perhaps sufficient differences to separate it off as a distinct but allied family, which would be the only other alternative.

STUDIES OF THE ARCHÆOCIDARIDÆ.

STRUCTURE AND PLATE ARRANGEMENT OF ARCHÆOCIDARIS WORTHENI AND OTHER SPECIES.

The species of *Archæocidaris* have for the most part been described from dissociated plates and spines, the genus having been based by M'Coy on such material. At least three species, however, have been based on more perfect material. The type of *Archæocidaris agassizii*, Hall, is in the Worthen collection at the University of Illinois, at Urbana, Illinois (see foot-note, page 136). This specimen is from the Burlington limestone, and as figured consists of a fragment of an interambulacrum with attached spines. The spines lie thickly over the test so as to hide most of the plates. In 6 specimens of this species which are in the Museum of Comparative Zoölogy (catalogue numbers 3032 to 3039) the fragmentary interambulacra are almost completely covered by the large, thickly associated spines. One of these specimens (catalogue number 3035) has the buccal pyramids in place, which structures have not been described in the species.

A second species, *Archæocidaris drydenensis*, Vanuxem, was described first as *Eocidaris*, then as *Archæocidaris* by Shumard, and later as *Eocidaris* by Hall (17). Dr Duncan (9) considers that *Eocidaris* is a synonym of *Cidaris*, having no distinctive characters; therefore the species in question cannot be included in that genus. The type, which is in the New York State Museum at Albany, I have not seen, but a cast of the type in the American Museum in New York would seem to be referable to *Archæocidaris*, where Keyes (24) includes it in his recent "Synopsis of Paleozoic Echinoids." This species has 7 columns of interambulacral plates, thus exceeding in this feature any other known species of the genus. The species has never been figured.*

Another species, *Archæocidaris wortheni*, Hall (15), was described from perhaps the best material known in any species of the genus. This material was in the Hall collection and is now in the American Museum of Natural History in New York. The specimens, which are from the Saint Louis group, Subcarboniferous, of Saint Louis, Missouri, consist of a large slab containing several more or less complete individuals; also several smaller specimens consisting of more or less complete tests, dissociated plates, jaws and spines. All the most complete specimens have 4 columns of plates in each interambulacral area.

The best specimen, which is free from the matrix, was figured by Hall.† This specimen is in a very fine condition of preservation. Hall's original figure, drawn by Meek, shows the general features, and additional features are shown in my plate 8, figure 43. This figure is oriented, as in Hall's original figure, for easy comparison when such is desired. Interambulacrum *A* at the ventral border of the corona has a row of 4 plates, *c*, *d*, *e*, *f*.§ Plate *c* of column 1 is nearly entire, but its ventral border has been partially resorbed by the encroachment of the peristome on the

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* It is an important matter of scientific information to know where the types of species and figured specimens are located; therefore in this paper I have given this information in regard to the species considered when known. The following species are not otherwise mentioned, but it is worth recording that the types are in the Illinois State Museum at Springfield, Illinois (see foot-note, page 207). *Archæocidaris edgarensis*, W. and M., *illinoisensis*, W. and M., *spiniclavata*, W. and M., and *Archæocidaris*, sp. undetermined, W. and M., jaws. (Geological Survey, vol. iii, vii, plate xxx, figure 16.) The types of the following species are in the Worthen collection at the University of Illinois, Urbana, Illinois (see foot-note, page 136): *Archæocidaris keokuk*, Hall, *mucronata*, M. and W., *shumardana*, Hall. The type of *Archæocidaris legrandensis*, Miller and Gurley, is in the private collection of Wm. F. E. Gurley, at Springfield, Illinois.

† Report of the Geological Survey of Iowa, vol. i, plate 26, figures 4*a* and 4*b*. Figure 4*a* has been frequently reproduced in text-books, as Zittel's and Nicholson's Manuals of Paleontology.

§ The ventral plates of this and other areas are only partially shown in the original figure.

corona. The fact that it has been resorbed is shown by the position of the tubercle, which lies nearer to the ventral edge, and also the fact that a line drawn through the right and left apices of the hexagon does not divide the plate equally, as in superjacent plates, but falls nearer the ventral than the dorsal border. On account of the alternation of position of adjoining columns the ventral plate of column 3 is a small plate, *d*, representing less than the upper half of a hexagon, just as plate *c* has less than half of the lower half of a hexagon. Plate *d* has no primary spine boss, it having been resorbed with the lower portion of the plate. The ventral plate of column 4 is again a large, three-quarters plate *e*, like plate *c* ; its ventral border has been considerably resorbed and the spine boss lies near the ventral edge. The lowest plate, *f*, of column 2 is wanting, but a vacancy in the specimen allows for its legitimate reconstruction, as indicated by the dotted lines. The relations of this resorption of ventral plates of the corona is shown especially clearly in *Cidaris florigemma* (plate 8, figure 47), where. on account of the size and ornamentation of the plates, their removal by resorption is strikingly apparent. One striking difference in these two types exists. In *Cidaris* (plate 8, figures 47 and 48), the smaller plates on the border of the corona have a large, central spine boss, and secondary bosses much as in complete plates further dorsally. It is evident that here there has been a readjustment of parts, so that though the original ornamentation was more or less resorbed with the ventral border of the plate, a new series of spine bosses have grown up to take the place of and occupy the same relative position as the original tubercles. In a young specimen of recent *Cidaris papillata* Leske (plate 9, figure 55) the spine tubercles are being resorbed together with the ventral border of the plates, and no readjustment has as yet taken place. In the specimen of *Archæocidaris* studied there was no evidence of a readjustment of tubercles in the ventral plates.

In ambulacrum *B*, of *Archæocidaris* (plate 8, figure 43), as in other ambulacral areas, the plates consist of two columns, *a b*, of small, low plates, each having two pores. The sides of the plates are parallel and the form very regular, more so than in species of the *Melonitidæ.*

In interambulacrum *C* we find in the ventral row of plates a condition like that described in area *A*. Plate *c* of column 1 is wanting, and the plate lying on its dorsal border is twisted dorso-ventrally, but the empty space for *c* remains, and it can properly be reconstructed, as indicated by the dotted lines. The ventral plate *d* of column 3 is present, and consists of less than the upper half of a hexagon, as in plate *d*, area *A*. It has no spine boss. The ventral plate *e* of column 4 is hexagonal, with its ventral border partially resorbed, as in the same plate of area *A*. The ventral plate *f* of column 2 is less than the upper half of a hexagon, like plate *d*, and like it has no spine boss. Areas *C* and *A* are therefore seen to be exactly alike ventrally and are mutually helpful, for plate *c*, which is wanting in area *C*, is present in area *A;* also plate *f*, which is present in area *C*, is wanting in area *A*.

Ambulacral plates are wanting in area *D*, but the space they occupied remains open.* In interambulacrum *E* there is a parallel but reversed condition in the ventral row of plates as compared with areas *C* and *A*. The ventral plate *c* of column 1 is not preserved, but its place remains vacant, and it is restored as shown by the dotted lines. This plate *c* is a small plate, being less than the upper half of a hexagon, like plate *d* in areas *C* and *A*. The initial plate *d* of column 4 is present as a hexagon, with its ventral border partially resorbed. The ventral plate *e* of column 3 is present as a small plate, less than the upper half of a hexagon, and shows what plate *c* should have been. Plate *f*, the ventral plate of column 2, exists as a hexagon, with its ventral border partially resorbed. Plates *d* and *f* have spine bosses in the original center of the plate, but on account of resorption lying nearer the ventral than the dorsal border.

In interambulacrum *G* the row of ventral plates is like the same row in area *E*. Plate *c* of column 1 is less than the upper half of a hexagon, as in area *E*. Plate *d* of column 4 is a hexagon, with its ventral border truncated. Plate *e*, the ventral plate of column 3, is wanting, but the place for it exists in the specimen, and it is introduced as indicated by dotted lines. Plates *c* and *e* have no spine bosses. Plate *f*, the ventral plate of column 2, in the specimen, is slightly twisted out of place, but it is restored to its natural position in the figure; its ventral border is somewhat truncated.

In ambulacrum *H* the plates are clearly preserved. In interambulacrum *I* the ventral row of plates is wanting, so no attempt is made to restore them in this figure. Ambulacrum *J* has the plates clearly preserved. In the specimen areas *A* and *C* have the same arrangement, and in these the fourth column is right-handed. This point is discussed later (page 220). In areas *E* and *G* a different but comparable arrangement exists in the ventral row, and in these areas the fourth column is left-handed. What the arrangement of area *I* would have been if perfect may be pretty safely assumed from the relative position of plates. From the position of plates in column 2 of area *I* it seems that the lowest plate of this series must be the ventral plate of the area, as in column 2 of area *G*. Therefore in the reconstruction, figure 44, this idea is carried out, and as a consequence the other plates of the ventral row are the same as in area *G*.

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*In making the drawing of figure 43, Mr Emerton did not have the specimen; but made his figure from detailed drawings of the specimen. By an oversight he included the ambulacral plates in area *D*, where they do not exist in the specimen.

The interambulacral plates of *Archæocidaris wortheni* have a large central perforated primary spine tubercle which bears a long smooth spine measuring from about 5 to 6.5 centimeters in length. In addition there is on the borders of the plates a row of small secondary spine tubercles. In plate 8, figure 43, by a mistake of the artist (see foot-note, page 216), the secondary spine bosses are too numerous and too prominent in each plate. They are represented more correctly for this species in the reconstruction (plate 8, figure 44). The spines belonging to these small tubercles have never been described in the genus. A specimen of *Archæocidaris wortheni* in the Museum of Comparative Zoölogy (catalogue number 3028, plate 8, figure 46), besides the large primary spines, shows the small secondary spines associated with the small tubercles on the borders of the plates. These small spines are smooth, acicular and measure from 2 to 2.4 millimeters in length. The enormous disproportion in size between the primary and secondary spines is shown in the figure, although from lack of space the entire length of a primary spine could not be given. The dotted lines in the figure represent a reconstruction of the primary spine from another specimen, the spine belonging to the plate figured, terminating by a fracture. Similar secondary spines are also shown in a specimen of *Archæocidaris agassizii* in the Museum of Comparative Zoölogy (catalogue number 3037).

The choice specimen of *Archæocidaris wortheni* described (plate 8, figure 43) not only has the ventral row of plates of the corona preserved almost entire, but also has the buccal pyramids and plates on the peristome preserved as well.* The pyramids lie opposite the interambulacra in each of the 5 areas. The pyramids of each area consist of two parts, as indicated by the median suture. While in contact when well preserved, the parts may become separated. The pyramids in this specimen are truncated orally as shown in the figure, but in other specimens, as seen in the American Museum and in a specimen of this species (catalogue number 3027) in the Museum of Comparative Zoölogy, they are bluntly acuminate orally. In one area, *A*, of the figure one side of a pyramid is restored as indicated by dotted lines; otherwise the outlines are exactly as in the specimen. The teeth, which should lie at the oral termination of the pyramids and between their apposed tips, are not preserved.

On the peristome the plates of the interambulacral areas are scale-like, imbricating adorally (plate 8, figure 43). The plates are largest on the outer border of the peristome and decrease in size toward the oral area, where also the number of plates is relatively less. These plates do not

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* In Professor Hall's original figure, as cited, the pyramids are shown, though I have been able to add something in regard to them. The plates on the peristome, however, are only indicated by a few dots showing no details.

seem to bear any relation to the 4 columns in the corona. They impinge upon the corona in a quite irregular manner, and in the most perfect area, *A*, are seen to be 5 in number on the margin. Comparing these interambulacral plates of the peristome with those of a recent specimen of *Cidaris tribuloides*, Lam., from Panama, in the collections of the Museum of Comparative Zoölogy (catalogue number 404, plate 8, figure 48), it is seen that the form is strikingly similar. Orally there is a single column of these interambulacral plates in *Cidaris;* but on the outer border, as pointed out by Lovén (27) some accessory plates are seen, as shown in the figure, and as also shown in *Cidaris papillata*, plate 9, figure 55, after Lovén (27).

The ambulacral plates of the peristome in *Archæocidaris wortheni* differ from the same plates of the corona in being drawn out in the longer axis, and they are somewhat irregular in shape, the plates of the corona being very uniform in size and shape. These plates of the peristome interlock apparently somewhat loosely on their apposed median border and laterally are drawn out in somewhat acuminate points. They have in all plates observed two pores, which are situated in one horizontal plane. No ambulacral plates were seen nearer the mouth than those represented. Such plates if existent might show the pores arranged in a dorso-ventral rather than a horizontal position in the plates. Comparing the ambulacral plates of the peristome of *Archæocidaris* with those of *Cidaris* (plate 8, figure 48), we find that in *Cidaris* they are more regular in form, relatively much larger both vertically and horizontally, and the pores are arranged vertically, overlying one another, instead of horizontally, as in *Archæocidaris*; also in *Cidaris* these plates imbricate strongly adorally.

In another species of *Archæocidaris*, from Peoria county, Illinois, in the Museum of Comparative Zoölogy (catalogue number 3029), the spines and plates of portions of the skeleton are very clearly preserved. On the plates of the corona the large primary spines are attached directly to the large central tubercles of the plates. Small secondary spines are abundantly preserved, attached to the secondary tubercles situated on the borders of the plates, as in *Archæocidaris wortheni* (plate 8, figure 46). A portion of the peristome is also preserved, showing imbricating interambulacral plates and elongate plates with two pores in the ambulacral areas. These plates of the peristome are largely hidden by a profusion of small spines which thickly cover the area.

The peristome and ventral border of the corona have never been described before in *Archæocidaris*, except in so far as Professor Hall's original figure of this same specimen shows it; also the plates of the peristome, I think, have not been figured in any Paleozoic genus, although they are described by Sir Wyville Thomson (39) in *Echinocystites;* therefore on account of its importance a restoration of this area is given in plate 8, figure

44. In this figure the areas are lettered as in the original figure 43. The ventral row of plates in area *I* is restored completely, as it does not show in the specimen. On account of the relative position of the plates I think that this row would have the same arrangement as in areas *E* and *G*, as discussed (page 216), and have so restored it. In the restoration the buccal pyramids are brought to an acuminate instead of truncated distal tip, and the ambulacral and interambulacral plates are carried up on to the peristome farther than they were seen in the specimen. Otherwise this restoration differs from the facts as shown in the specimen only by being made regular in outline, thus doing away with local distortion caused by the processes of fossilization.

It has been shown in several genera that in the development of the interambulacrum there is a single plate at the ventral termination in the young, or in both the young and adult of some species. From this as a beginning during progressive growth, there is an addition of new columns of plates until the full number characteristic of the adult is attained.* It is further shown that this initial plate is ordinarily resorbed, together with more or less succeeding plates, by the encroachment of the peristome. Such being the case, it is interesting to inquire into what was the structure of *Archæocidaris* before resorption took place and how the four columns characteristic of the adult interambulacrum developed. In plate 8, figure 45, an endeavor is made to reconstruct these first plates, doing so by the laws of growth as established in other genera in the present pàpers. Around the mouth we must suppose that there existed a row of 10 ambulacral plates, for such is found in the development of *Cidaris* (figure 3, page 234) and *Strongylocentrotus* (plate 3, figure 8) and is known in the adult of the oldest known echinoid, *Bothriocidaris* (figure 4, page 234). Whether this first row of plates in *Archæocidaris* was succeeded by another row of 10 ambulacral plates, as in *Bothriocidaris*, as shown by Schmidt (37), or whether it had an accelerated development, as in *Cidaris* (figure cited) and skipped the second row, we have no means of telling. I prefer to leave it as one row, as that is in accordance with the condition of most genera observed. Succeeding the first row of ambulacrals, we suppose a second row, in which there are two ambulacrals in each area, and, in addition, a single interambulacral plate, 1′, exists as the beginning of that part in each of the 5 areas.† In the succeeding rows as added, the ambulacra continue as two columns of plates, *a*, *b*, as in the adult. In the third row there are in the interambulacra 2 plates in each area corresponding to the condition existent in all genera above *Bothriocidaris.*

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* See studies of *Melonites, Oligoporus, Pholidocidaris, Lepidocidaris, Lepidechinus, Cidaris, Strongylocentrotus,* and *Bothriocidaris,* all illustrated by figures in the plates or text.

† Compare this with plate 3, figures 8–11; plate 6, figure 27; plate 7, figure 42, plate 9, figure 54, and figures 1, 3 and 4, pages 164 and 234.

These two plates, 1 and 2, in the several areas of *Archæocidaris* by additions form the two adambulacral columns of plates (compare with *Melonites*, plate 2, figure 2). In the next row of interambulacrals there are 3 plates, plate 3 being the initial plate of the first median column of interambulacral plates. In the next row above initial plate 3 we find in the 5 areas the introduction of a fourth plate, 4, which is the beginning of the fourth column of plates. It is seen in areas *A* and *C* that the fourth column originates in its theoretically correct position, with two columns on the left and one on the right. In areas *E*, *G* and *I*, however, the fourth column is represented as beginning on the left of the center, with one column of plates on the left and two on the right.

Continuing dorsally, we find that 4 columns continue to be formed, and no more are known in this species. In the first row added above the introduction of the fourth column in this diagram (plate 8, figure 45) a circular dotted line bisects the plates. All below or on the ventral side of this dotted line is reconstruction, but that portion which lies above the line represents the condition as actually observed in the specimen of *Archæocidaris* from which plate 8, figure 43, was drawn.* The plates *c*, *d*, *e* and *f* above the dotted or resorption line in plate 8, figure 45, in the several areas correspond in form and position exactly with those of plate 8, figure 44. It is to be observed that in order to make these plates come in their proper order it was mechanically necessary to have column 4 right-handed in its development in areas *A* and *C* and left-handed in areas *E*, *G* and *I*. It is also to be noted that, arranging them as I have, the columns are introduced precisely as in *Melonites* (plate 2, figure 2, and figure 1, page 164), and carrying out the relative proportion in size, as seen in other genera, the number of plates introduced in the reconstruction is just sufficient to build the required number of columns and to meet around what was the border of the peristome at an early stage in growth.

STRUCTURE OF LEPIDOCIDARIS SQUAMOSUS.

Messrs Meek and Worthen (31) founded the genus *Lepidocidaris* for the single species *L. squamosus*, M. and W. The type of the species and genus (plate 7, figure 41), which was in the Wachsmuth collection, is now in the collections of the Museum of Comparative Zoölogy (catalogue number 3026). The species is from the lower Burlington limestone of Burlington, Iowa. Besides the type, there are several fragmentary specimens of the species in the Cambridge museum. This species differs in many features from *Archæocidaris*, so that Meek and Worthen's genus *Lepidocidaris* should certainly stand, and I think Professor Keyes is mistaken, when in

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* Except for restoration of area *I*, which is reconstructed, as shown in plate 8, figure 44.

his "Synopsis of Paleozoic Echinoids," he includes it under the genus *Lepidechinus.* There are essential differences in the form of the interambulacral plates, the ornamentation of the same, and the arrangement and form of the ambulacral plates from *Lepidechinus rarispinus*, Hall, as I can safely assert, having studied Hall's types and also other specimens of the species (plate 7, figure 42). *Lepidocidaris squamosus* also differs essentially from *Lepidechinus imbricatus*, which is the type of the genus, judging from Professor Hall's description, although unfortunately the species has never been figured.

In Meek and Worthen's figure of *Lepidocidaris squamosus* the axes were incorrectly oriented, as they had nothing to guide them in fixing axes but details of plate arrangement, and this method of orientation was unknown. In plate 7, figure 41, the orientation is corrected. The interambulacral plates of *Lepidocidaris squamosus* are comparatively thin and the imbrication is slight.

The ambulacral plates of *Lepidocidaris squamosus* are small, low, and above the ventral border fail in many cases to pass across the half-area to which they belong. This feature is a distinction from either *Archæocidaris* or *Lepidechinus*, and is similar in method, though not quite so complete in degree, as in *Palæechinus*, as recently emended by Dr Duncan (8) and shown in *P. gigas* (plate 7, figure 39). It also reminds one strongly of the condition seen in developing *Oligoporus* (plate 6, figure 25).

At the ventral border of the interambulacrum, as far as preserved (plate 7, figure 41), there are 5 columns of plates, although their outlines are somewhat indistinct. The sixth column is introduced by a pentagonal plate 6. This column has 2 columns on the left and 3 on the right at its point of origin. No heptagonal plate bordering pentagon 6 can be made out on account of the imperfections at that area. In the third row above pentagon 6, the seventh column is introduced by the pentagon 7 with a heptagonal plate, *H*, on its left and 3 columns of plates on either side at the point of origin. The eighth and last column added, as far as the specimen shows, originates in pentagon 8, in the second row above pentagon 7. This eighth column at its origin has 3 columns on the left and 4 on the right. A heptagonal plate, *H*, lies on the right of the terminal pentagon. This is the only entire specimen known, so that we cannot tell whether more columns were added or not. From the contour of the specimen it appears that its dorsal portion could not have reached much more than to the ambitus; therefore it is possible that more columns of plates will be found to be characteristic of the species if more perfect material is found.

Lepidocidaris is evidently a near ally of *Archæocidaris*, and it is interesting to find that the plate arrangement traced in the Melonitidæ can be traced equally well, following the same laws of growth, in this genus, which we may take in regard to this feature as representing the typical forms of the family. In the allied family, the Lepidocentridæ, as represented by *Lepidocentrus* and *Lepidechinus*, the development is so accelerated and the individual plates are so peculiar in form that in details of plate contour and arrangement they make a law unto themselves.

NOTES ON XENOCIDARIS.

The genus *Xenocidaris*, Schultze, is known only from dissociated spines. *X. clavigera*, Schultze (38), the type of the genus, is from the Devonian of Gerolstein, Eifel. This type material, consisting of some 30 spines, is in the L. Schultze collection, in the Museum of Comparative Zoölogy (catalogue number 3044). Besides the types, a few other specimens of this species are in the same collection.

The distal ends of the spines are extensively enlarged. They are truncated, the apex being elevated, flat or reëntrant; it is also spinulose, showing much variation in different spines. The sides of the spines near the distal end are plicated, but in various degrees in different spines. The commoner variations of this protean type are shown well in Schultze's figures.

The affinities of *Xenocidaris* are questionable, as it is known only from such limited material. Provisionally it may be retained in the Archæocidaridæ, as that is the only family of Paleozoic Echini characterized by large and ornate spines.

Studies of the Lepidocentridæ.

GENERAL CHARACTERISTICS.

The Lepidocentridæ is a family of Echini associated with the Archæocidaridæ and characterized by possessing strongly imbricating plates and a highly accelerated development in regard to the rapid rate of introduction of interambulacral columns. In this feature it is the most accelerated of any Paleozoic Echini. The peristome is small and the single initial plate of the interambulacrum is retained in the adult (*Lepidechinus*).

Dr Duncan in his "Revision" (9) includes the genera of the Lepidocentridæ in the Archæocidaridæ, but this seems a mistake, as they are a very distinct and concrete group of forms, and are separated by both Lovén (25) and Zittel (44).

STRUCTURE AND PLATE ARRANGEMENT OF LEPIDOCENTRUS.

The genus *Lepidocentrus*, Müller, has not been described from this country, though it is quite close to *Lepidechinus*. In the Museum of Comparative Zoölogy is a specimen (catalogue number 3040) of *Lepido-*

centrus mülleri, Schultze, from the Middle Devonian of Muhlenberg near Gerolstein, Eifel. This specimen is in the Ludwig Schultze collection and is the original type of Schultze's species, being figured in his work on Eifel fossils (38), (plate 13, figure 1).

The ambulacral areas of *Lepidocentrus mülleri* (figure 2) consist of 2 columns of narrow, low, quite regular plates, each perforated by 2 pores. The clearest ambulacrum of the specimen is that seen at the right of the figure. The ambulacrum *B*, which should exist between the 2 interambulacra figured, *A* and *C*, has been shoved out of view, except in the ventral portion, by the lateral movement of the interambulacra.

Two interambulacra are quite well preserved, as shown in the figure, and on the other side of the specimen the impress of the plates of two other areas can be more or less made out. All interambulacra consist of a large number of columns of plates at what I take to be the dorsal portion, and all are reduced to few columns at the ventral portion, as in *Lepidechinus* and other genera.

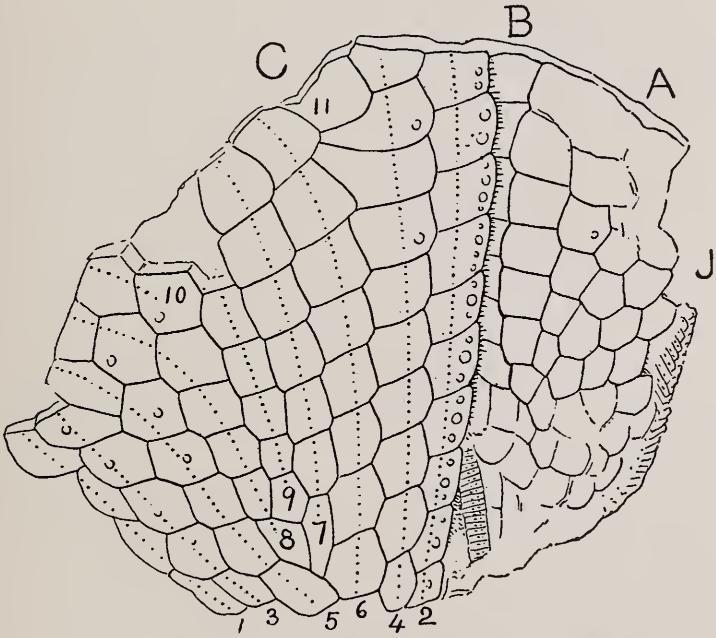

FIGURE 2.—*Lepidocentrus mülleri*, Schultze. (Life size).

At the ventral border of area *C*, as far as preserved (figure 2), 6 columns of plates exist, as indicated by the numbers and dotted lines; passing dorsally, new columns are rapidly added, as in *Lepidechinus* (plate 7, figure 42), columns 7, 8 and 9 originating almost simultaneously. The tenth and eleventh columns do not originate until much later than the ninth, and the eleventh originates much too far to the right, according to the ordinary laws of growth, it having at its point of origin eight columns on the left and but two on the right. This highly irregular position may be compared with the similar irregular position of the seventh column in *Melonites septenarius* (plate 9, figure 49). It is noticeable in *Lepidocentrus mülleri* that the initial plates of newly added columns do not show the pentagonal form which is shown to be characteristic of most Paleozoic Echini, and the same remark applies more or less closely to *Lepidechinus* (plate 7, figure 42) and *Pholidocidaris* (plate 9, figure 54).

In the large number of columns of interambulacral plates attained, this species is one of the most extreme types of all echinoids, a similar condition being seen in *Lepidechinus rarispinus*, Hall, and *Melonites giganteus* Jackson, (plate 5, figure 21), both of which have 11 columns (see systematic table facing page 242).

No genital or other plates indicating the dorsal or ventral area being existent, this specimen of *Lepidocentrus mülleri* has to be oriented by the direction of introduction of columns (compare with *Melonites*, plate 2, figure 2, and *Lepidechinus*, plate 7, figure 42). This being done, it is seen (figure 2) that the interambulacral plates are strongly imbricated adorally and laterally; the median plates overlapping those on either side and adambulacrals overlapping adjacent ambulacrals. Accepting this method of orienting axes as correct, and it seems to be clearly proved by the numerous types studied, it follows as a consequence that Schultze's (38) original figure of this specimen was incorrectly oriented. Müller's (35) figure of *Lepidocentrus rhenanus*, Beyrich, was also incorrectly oriented, as proved positively in this case by the presence of jaws; and Professor Zittel, in his recently published "Grundzüge der Palæontologie," has copied the figure and corrected the orientation.

The two species, and perhaps the two specimens mentioned, are the only ones in the genus in which a comparatively complete test is known, and this incorrect orientation in the figures cited has apparently led to a mistake in regard to the direction of imbrication of the plates. We find the statement by Dr Duncan (9) and others that the interambulacral plates of *Lepidocentrus* imbricate aborally and laterally, whereas it should be corrected to read adorally and laterally. The same authority (9) describes the interambulacral plates as hexagonal. In *Lepidocentrus rhenanus*, Beyr., they are nearly or quite hexagonal, with the corners rounded, as figured by Müller; but in *L. mülleri* (figure 2) they are more nearly rhombic in form and none are strictly hexagonal; in *L. eifelianus* they are scale-like, with rounded rather than hexagonal sides. I feel it necessary to make a point of correcting this statement because the form of the plates in this genus is considered as an aid in the systematic classification of the three species.

In the study of the plates of *Lepidocentrus mülleri* help has been obtained from the large number of dissociated interambulacral plates in the Schultze collection. These plates are the types of Schultze's original work, and are in the Museum of Comparative Zoölogy. One set of plates is from the Devonian of Rommersheim, near Prum, Eifel (catalogue number 3041), and another set is from Gerolstein, Eifel (catalogue numbers 3042 and 3045). The original types of the spines, presumably primaries from interambulacral plates, are also in the collection. They are from Gerolstein, Eifel (catalogue number 3043).

The interambulacral plates in the upper part of the test (figure 2) are all nearly rhombic in outline, and ventrally the plates have the angles of the rhomb truncated by curving additional sides. It has been shown that in *Melonites* the newly formed or young plates at the dorsal border of the corona are rhombic in outline (plate 3, figure 13, and plate 5, figures 20 and 21). A similar condition has been approached in *Oligoporus* (plate 6, figure 31) and in *Palæechinus* (plate 7, figure 36). It appears, therefore, that the plates of *Lepidocentrus mülleri* throughout the life of the individual retain nearly or quite the simple character which is seen in young, newly added plates of unspecialized types. (For further discussion see page 228.)

The interambulacral plates of *Lepidocentrus mülleri* have a single comparatively large primary spine boss, occupying various positions on the plate, though none were seen in the center, the usual place for such bosses. Secondary spine bosses are scattered over the surfaces of the plates. This condition of primary and secondary bosses is interesting for comparison with the similar condition shown by Meek and Worthen (31) in *Pholidocidaris irregularis*, another aberrant echinoid, but in a quite distinct family (see table of classification facing page 242). The spines of *Lepidocentrus mülleri* are small, acicular and swollen at the base.

In *Lepidocentrus eifelianus*, Müller, we have another, but quite closely allied species, which is known only from dissociated plates. Plates of this species from the Devonian of Nohn, Eifel, are in the Schultze collection in the Museum of Comparative Zoölogy (catalogue number 3068), and spines attributed to the same (catalogue number 3069); also a large series of plates from the Devonian of Rommerscheim (catalogue number 3061). This species differs from *L. mülleri* in having much thinner plates, and also the plates are more rounded in form, exceeding in this feature any plates found in that species. It is therefore apparently more specialized in this peculiar matter of plate form. The spines do not differ essentially from those of *L. mülleri.*

NOTES ON PERISCHODOMUS.

The genus *Perischodomus* is known only from two species. One, *P. illinoisensis*, Worthen and Miller (42), is imperfectly known. The type is in the Illinois State Museum at Springfield, Illinois (see foot-note, page

207). The other species, *P. biserialis*, M'Coy, has been well illustrated by Keeping (22). The type of M'Coy's and Keeping's researches on this species is in the Woodwardian Museum at Cambridge, England. A specimen of this second species from the Carboniferous of Hook Point, county Wexford, Ireland, is in the Museum of Comparative Zoölogy (catalogue number 3071). The specimen consists of a portion of an interambulacrum and a single ambulacral plate. The plates are rounded on their borders and imbricate strongly aborally, as described. The introduction of one column of interambulacral plates, the fifth, is shown.

STRUCTURE AND DEVELOPMENT OF LEPIDECHINUS.

The genus Lepidechinus was founded by Professor Hall (16) for the reception of a species with imbricating plates. *Lepidechinus imbricatus*, Hall, the type of the genus, has not been figured or published from original observations, so far as I can find out, except in the original description. Another species, *Lepidechinus rarispinus*, was later described by Hall (17) and a figure given. All the known specimens are sandstone casts. Jaws have not been previously described in the genus.

Professor C. E. Beecher, of New Haven, kindly loaned me a valuable specimen of *Lepidechinus rarispinus* from the Waverly sandstone, Subcarboniferous, of Warren, Pennsylvania. This choice specimen (plate 7, figure 42) is a cast of the ventral side. One interambulacrum is very clear, and it with adjacent ambulacra, jaws, and some plates of the peristome are shown in the accompanying figure.

At the ventral border of the interambulacrum there is a single initial plate, 1′ (plate 7, figure 42). This plate has a sharp apex dorsally, two inclined, but very short sides at the contact with the bordering ambulacra, and ventrally is truncate. *Lepidechinus* and *Pholidocidaris* (plate 9, figure 54) are the only genera of Paleozoic echinoids in which I have seen the single initial plate, although every evidence of its presence has been observed in *Melonites* (plate 3, figure 10) and *Oligoporus* (plate 6, figure 26). In *Melonites* and *Oligoporus* the supposed ventral plate with part of the ventral border of the two succeeding plates was removed by resorption; but here we have a case in which resorption at most removed only part of the initial plate of the area. In *Lepidechinus* the second row of interambulacral plates consists of two quite irregular plates, 1 and 2. Part of this irregularity may be due to imperfections of preservation, as the outlines, especially of plate 2, are quite difficult to make out in this sandstone cast. Plates 1 and 2, by addition of succeeding plates, form the two adambulacral columns, as in *Melonites* (plate 2, figure 2). These adambulacral plates, on account of the peculiar scale-like form of the plates, are not so regularly pentagonal as in *Melonites* and similar forms. In the third row of *Lepidechinus* the third column of plates originates in plate 3 and forms the first added median column of interambulacral plates. In the next row the fourth column is introduced by plate 4, which has 2 columns of plates on the left and 1 on the right, as usual in *Melonites.* In the fifth row the fifth column is introduced by plate 5, with 2 columns on either side. Initial plate 5 impinges on the dorsal side of initial plate 3. The sixth column is introduced so quickly that its initial plate 6 extends down into and becomes part of the fifth row. The seventh column is also introduced very quickly, its initial plate 7 truncating the dorsal border of plate 5. The eighth and ninth columns originate almost simultaneously in plates 8 and 9, which both impinge on the dorsal border of initial plate 7. It is to be observed that in *Lepidechinus* the initial plates of columns are not pentagonal with adjacent heptagonal plates, as in *Melonites* and most other genera of Paleozoic Echini, the scale-like imbricating character, together with the rapid introduction, seeming to do away with the usual forms of the plates. From the initial plate 1′ to the introduction of the fourth column in plate 4, the development of *Lepidechinus* (plate 7, figure 42), excepting for the scale-like form of its plates, is like that traced in *Melonites* and *Oligoporus.* The later added columns of *Lepidechinus*, however, present a striking difference in their extremely rapid introduction, surpassing any other known form of Palæechini, except *Lepidocentrus mülleri* (figure 2, page 223). In this feature it may properly be considered a highly accelerated type, very early acquiring features which appear much later in the nearest allied forms.

The ambulacral plates of the corona of *Lepidechinus rarispinus* (plate 7, figure 42) are in 2 columns, each plate of which extends quite across its own half ambulacrum. The plates have 2 pores and a prominent pit, representing a spine tubercle. Smaller tubercles may have existed, but they were not made out. On the peristome faint traces of the ambulacral plates can be made out, as shown in the figure; they are principally indicated by the pores and spine tubercles.

Prominent buccal pyramids are present orally, lying opposite each interambulacral area, but the actual teeth are not shown.

There are 2 specimens of *Lepidechinus rarispinus* in the American Museum of Natural History, New York, and they are the original types from which the species was described. These specimens are smaller and have smaller plates than the specimen just described. They show 11 columns of plates, as originally described, and the number of columns increases rapidly in passing from the ventral border dorsally, as in Professor Beecher's specimen. I cannot say, not having observed it at the time, whether or not the arrangement is exactly as in plate 7, figure 42, but should say that it was essentially the same. In one of these specimens, from Licking county, Ohio, which is preserved entire, the ambulacra are much broader on the ventral aspect and are decidedly narrower near the dorsal area. The other specimen,* which is from Meadville, Pennsylvania, is flattened on the rock and represents the dorsal portion of the corona. The plates on the lower or ventral portion of this specimen are rounded and imbricating, but near the dorsal portion they are hexagonal and less imbricate, and close to the dorsal termination of the areas are nearly, and in some cases perhaps actually, rhombic in form, closely resembling the plates of the same region in *Melonites* (plate 3, figure 13); they are very small and need to be studied critically.

This rhombic and hexagonal form of the dorsal or newly added plates of *Lepidechinus rarispinus*, it seems, is an important character, for in it we have newly added or, so to speak, young plates which have characters seen normally in less specialized genera. The peculiar scale-like and imbricating character appears later, when the plate has been considerably removed from the dorsal area by the intercalation of later added plates. An important fact bearing directly on this problem is Mr Agassiz's observation (Challenger Echini, page 75), that young *Phormosoma* and *Asthenosoma* † show only the slightest possible lapping of the edges of the plates of the corona, and it is only in somewhat later stages that the lapping of the sutures becomes apparent. This change in the form of plates in *Lepidechinus* reminds one strongly in the implied principles of growth of the change in form of plates of some crinoid stems. In modern *Pentacrinus* and *Metacrinus* the plates of the older part of the stem are nearly round; but the plates close up under the calyx, which are the new, last added plates, are strongly pentagonal, resembling closely the form of plates seen throughout the length of the stem in the Jurassic genus *Extracrinus.* We have in this structural development of the crinoid stem apparently a direct phylogenetic feature, in which the young, newly added plates throughout the life of the individual resemble the plates of the entire stem in ancient representative types. It is a curious and important feature of stages in growth—a sort of continual rejuvenation in a localized part—which has not, so far as known, been made use of in phylogenetic studies. In *Lepidechinus rarispinus* I would venture the suggestion that the rhombic and hexagonal plates of the dorsal area in a measure have phylogenetic significance and indicate that the species was derived from forms which did not have imbricating plates. This is in accordance with what we might

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* This specimen is the original of plate 9, figure 10, of the Twentieth Report, New York State Cabinet.

† Recent deep-sea members of the Echinothuridæ.

expect, that forms with scale-like imbricating plates are specialized not primitive types.*

CONCLUSIONS.

GENERAL RESULTS AND THEIR BEARING.

Under conclusions I would first consider the general results arrived at in these studies and the bearings of the same. In the second part a new classification is offered as the result of this investigation. In the preceding pages the facts have been described and adhered to as closely as it was in my power to do. Some conclusions are introduced, but only such as seemed fully warranted and endorsed by the facts. In this chapter on "General Results and their Bearing" I introduce some more theoretical conclusions which from their nature are not so capable of proof and which I purposely avoided in the main body of the text.

The late Professor Sven Lovén, in his important work Echinologica (27), says on page 17:

> "In all the Echinoidea the growth of the corona is effected by new plates being successively added at the aboral termination of the ambulacra and the interradia, and by their increasing in size and solidity. As long as the animal lives, there is at work, more or less, in every part of its frame a continuous movement of reabsorption and renewal, of taking on one form and losing it for another, all in accordance with the morphological canon of the species, and this process is perhaps nowhere more conspicuous than in the corona of the Cidaridæ and Echinidæ."

This statement, if accepted without careful consideration, might be taken to mean that from the study of the corona of an adult we could tell nothing as to what changes it had passed through and what was the condition of the young, and this, as I think, I have proved would not be true. To analyze Professor Lovén's statement, all addition of plates to the corona takes place dorsally close to the genital ring; therefore the plates at this area are the youngest plates and all other plates of the corona are older in progressively increasing degree as we pass ventrally. Plates increase in size and thickness because the plates of the test are really internal structures and may receive additions by increment on the proximal and distal aspects as well as on the sides of the plates. A good example of this is seen in the initial plate 1′ of the interambulacrum of modern *Echinarachnius* or the Devonian *Lepidechinus* (plate 7, figure 42). When first formed this plate must have been very tiny, but in an adult it is relatively large, but still retains about the same angles of contour of this

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*Since the above was written Mr Charles Schuchert, of the National Museum, generously handed over to me for inspection some very perfect specimens of *Lepidechinus* which Professor Beecher had loaned him for study. This material corroborates what statements have been made, and also shows many additional details of structure.

plate as seen in young stages of other genera.* There is at work a continual resorption and renewal, a taking on of one form and losing it for another, etcetera. This at first sight seems to work havoc with any possibility of following stages in growth from an adult corona, but we think not for the Palæechinoidea in most cases, at least. Resorption takes place principally at the ventral border of the corona, being a consequence of the encroachment of the peristome. This is markedly seen in *Strongylocentrotus* (plate 3, figures 8, 9), *Cidaris* and *Archæocidaris* (plate 8, figures 43, 47 and 48, and plate 9, figure 55). In other cases little or no ventral resorption takes place, as in most of the Exocyclica, *Pholidocidaris* (plate 9, figure 54) and *Lepidechinus* (plate 7, figure 42). Resorption in other parts of the corona as understood would for the most part be the resorbing of one set of surface spine bosses (and concurrently the spines themselves, probably) and replacing them by another set of perhaps different form or number, as in *Cidaris* (discussion, page 215). It is possible that the outline of plates may change in this process of resorption and growth. For example, in *Melonites* (plate 3, figure 14) the initial plate of column 8 when young may have had the normal pentagonal form, as in figure 15, and later have taken on the peculiar hexagonal form shown in figure 14. This is a kind of change which we cannot prove one way or the other from the study of the adult. The plates themselves only disappear by resorption very rarely. Professor Lovén has shown in his "Etudes" (plate 51) that in the adult of *Arachnoides placenta* L. the single initial plate of the interambulacra is retained in only one area, whereas in the young this plate exists in all 5 areas. At the same time the initial row of primitive ambulacral plates are retained throughout life. This is a case in which 4 initial interambulacral plates have apparently disappeared by intercoronal resorption. No other case of removal of plates of the corona by resorption has been met with excepting that caused by the encroachment of the peristome. On account of the very definite form of coronal plates seen throughout species, genera and families of Paleozoic Echini, I think it may be properly assumed that while plates grow by enlargement, the relative form of plates in this group is constant throughout the life of the individual.

Professor Lovén (25) adopted a system of notation of interambulacral plates of the corona in which he numbers the several plates as added according to the row in which they occur. The system of notation adopted in this and the preceding paper differs from his in that the column rather than the row is the basis of numbering. In the accom-

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* The progressive increase in size of this first plate, without any considerable change in form I have traced in a quite complete series of developing *Echinarachnius parma*, varying from a few millimeters in diameter to the completed adult. The same fact may be traced in a number of Professor Lovén's figures of developing Echini (see his "Études").

panying figures interambulacral plate 1′ is the equivalent of Professor Lovén's plate 1, and plates 1 and 2 are the equivalents of his plates 2. He does not figure in his "Études" any genera with more than two columns of plates, and therefore no further comparison with his notation needs to be made.

The later or postembryonic stages in growth in animals are most important to study, from the light they throw on morphology and the ontogeny of the individual, as well as the phylogeny of the group. This line of investigation has yielded most fruitful results and needs no excuse. There are two methods of studying stages in growth. One, and obviously the best, is to get actual young in progressively advancing stages in growth. The other method, which has been employed in some groups, is to ascertain the stages through which an animal has passed by studying the form and lines of growth of relatively older or adult individuals. This method of study has been employed in mollusks, brachiopods and somewhat in corals. Good examples in which the condition of the young may be ascertained by studying lines of growth are *Nautilus*, *Vermetus*, *Hinnites* and *Lingula.* In crustacea which shed the hard cutaneous covering with advancing age, actual young must be had for a study of the development.

In echinoderms the conditions are somewhat complex, and vary in different parts of the skeleton. Purely internal hard parts, as teeth, perpendicular supports between the upper and lower sides of the test, as in *Meoma*, etcetera, must increase in size by a combined process of resorption and growth, such as we get ordinarily in the bones of a vertebrate, and probably could not by any means be made to yield stages when studied in an adult. The plates of the corona of an echinoderm are quite a different matter, however. These plates, especially the interambulacral, are found at quite definite positions in the corona, as shown in *Melonites* (plate 2, figure 2) and other genera. While the actual form of the plates may be modified by growth and sometimes by resorption, the existence of the plate in itself is an important factor, even if it has sometimes suffered alterations. Professor Lovén has shown (27) from a study of actual young, that certain plates of the corona, which make up the two interambulacral columns of modern Echini, occur and apparently originated at stated intervals in the development of the individual,* and he compares these young plates with plates found at the ventral border of adult types, the Clypeastroids and Spatangoids, which have similar plates. It

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*See Lovén's figures in the "Echinologica" of *Goniocidaris*, *Strongylocentrotus* (reproduced in this paper, figures 3 and 5, page 234, and plate 3, figures 8 and 9); also *Echinus*, and especially a young Echinoid on page 11 of his paper. In this last figure Lovén shows that the corona at an early stage consists of the first row of 10 ambulacral plates, succeeded by the 5 initial plates of the interambulacral areas, no other coronal plates apparently having yet appeared.

is merely carrying this principle further, and I think is straining no argument, to say that the introduction of columns of plates, both interambulacral and ambulacral, in *Melonites* (plate 2, figures 2 and 4), *Oligoporus* (plate 6, figure 25) and other types, indicate stages in growth through which the individual has passed in its development.

Accepting this principle, that stages in growth may be ascertained by a study of the adult, it is necessary to see what are its limitations. It is the plates themselves, and not their form, which are claimed as marking stages. The outlines of plates during increase in size may suffer changes, as discussed, but in Palæechini it does not seem that they could have altered much, for the form, especially of interambulacral plates, is very definite in almost all cases (see *Melonites*, plate 2, figure 2), and is just that form which is required by the mechanical conditions of impact, which conditions would have been nearly or quite the same in the young as in the adult. The surface ornamentation of plates cannot probably be used in the study of stages of an adult, as it is subject to much alteration, as pointed out by Professor Lovén (27). From a study of the adult we can ascertain the anatomy of the initial beginning of the corona, at least in general terms, when no resorption has taken place, as in *Echinarachnius* and *Lepidechinus* (plate 7, figure 42), or if the peristome has by its advance resorbed the ventral border, we then have the ventral border wanting to a greater or less extent, as in *Melonites* (plate 2, figure 3), *Archæocidaris*, and *Cidaris* (plate 8, figures 44, 45, 47, 48, and plate 9, figure 55).

Professor Lovén in his "Echinologica," page 18, describes the ambulacral plates of echinoids as forming rapidly and from the pressure caused by their own increase and that of the interambulacra, the plates come gradually to change their place relatively to the interradials and glide downwards toward the stomal region, where by resorption they are discharged, as it were, through the outlet of a river into the buccal membrane. This gliding downward I confess I cannot see in any of the types studied. If it took place, how could the primitive first row of ambulacrals be retained around the oral orifice of an adult, as in *Bothriocidaris* (figure 4, page 234) and in *Arachnoides?* Also, if this gliding down took place, how could we in an adult find stages through which ambulacral areas had passed in their development, as shown in *Melonites* (plate 2, figures 2 and 4), *Lepidesthes* (plate 9, figure 53) and *Oligoporus* (plate 6, figure 25)? Or how could fan-shaped ambulacral plates exist at definite positions, as in *Oligoporus missouriensis* (plate 9, figures 50, 51)?

Ambulacral plates in echinoids, on account of their relations to the ambulacral tube-feet, seem to be more important structurally than interambulacral plates, which latter, so to speak, are developed to fill intermediate space; therefore the greater importance, it seems, should be attached to ambulacral areas and their variations. Ambulacral areas originate in the young as 2 simple plates in all known Echini excepting *Melonites* and *Lepidesthes*, where they appear to originate as 4 plates,* and also perhaps, excepting *Pholidocidaris*. The addition of more columns of plates, as in *Oligoporus*, or the production of compound plates, as in *Strongylocentrotus*, takes place during the later stages in growth of the corona, as shown by Mr Alexander Agassiz (1), Professor Lovén (27), and in the present paper. Therefore two columns of plates may be accepted as the usual characteristic of the whole class, which finds its representative in the majority of adults, in nearly all young, and in the adult of the simplest and oldest known type, *Bothriocidaris*.

Interambulacral plates, as stated, are considered of secondary importance in the development of the corona, but they yield most important facts, and especially in the Palæechinoidea are useful in separating and tracing the systematic relationships of species and genera. Interambulacral areas in all echinoids, as formulated by Professor Lovén (27) and as shown in several genera in this paper, originate ventrally in a single plate. This single plate is shown in the young, and in the adult where no ventral resorption of the corona has taken place.† Only one genus is known which has a single column of interambulacral plates in the adult, and that one is *Bothriocidaris*. This Lower Silurian genus therefore assumes especial importance, for the development of both ambulacra and interambulacra and the geological position of the type all point to it as representing the simplest known and, within the limitations of the group, perhaps the simplest conceivable echinoid.

The figures 3, 4, 5, page 234, show the relations of *Bothriocidaris* as a type to *Goniocidaris*, which represents one great group of Echini characterized by 2 columns of ambulacral and interambulacral plates. For representatives of the other group of Echini, characterized by 2 or more columns of ambulacral and 3 or more columns of interambulacral plates, reference should be made to the figures of *Melonites*, *Oligoporus*, *Archæocidaris*, *Lepidechinus* and other genera, illustrated in figure 1, page 164; figure 1, page 191, and accompanying plates. Attention is also directed to the systematic classification table facing page 242. The initial plate 1′ of *Bothriocidaris*, figure 4, does not have an apex dorsally, as in all other Echini, but this is obviously the result of the dynamic conditions, for *Bothriocidaris* does not have two plates in the second row like all other known

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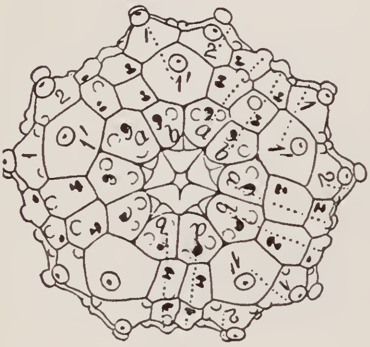
* Four plates are always found at the ventral border of *Melonites*, but some resorption of the corona has taken place, and it is possible that the 4 plates would be found to pass into two, as in *Oligoporus*, if young specimens could be obtained, as discussed on page 142.

† Except in *Arachnoides*, as discussed on page 230, where 4 initial interambulacral plates have disappeared in the adult from intercoronal resorption.

genera.* In this figure of *Bothriocidaris* the two pores in the ambulacral plates are arranged in a horizontal plane. This arrangement, according to Jaekel (20), is incorrect, and he figures a specimen with the pores lying in a vertical plane. Jaekel's figure would not serve my purpose, so I copied Schmidt's, and of course could not properly alter the position of the pores.

In *Goniocidaris* (figure 3) there is a single row of 10 ambulacral plates around the mouth instead of 2 rows, as in *Bothriocidaris* (figure 4). Succeeding this row there is a row of 10 ambulacral and 5 interambulacral plates, as in *Bothriocidaris*. In the third and succeeding rows of *Goniocidaris* there are 10 interambulacral plates (figure 5) instead of 5, as in *Bothriocidaris*. In adult *Goniocidaris* and other members of its family the ambulacral plates are low, with 2 pores, and many plates impinge on a single interambulacral plate (plate 8, figures 47, 48); also the interambulacral plates of the adult are nearly or quite pentagonal in form. In the young (figure 5), on the contrary, the ambulacral plates are nearly as high as the interambulacral; further they are hexagonal and have but a single pore. The interambulacral plates of the young are hexagonal (figure 5) instead of pentagonal. The relative form of the plates in young *Goniocidaris* is almost exactly the same as in the primitive type, *Bothriocidaris* (figure 4). The Cidaridæ are practically unchanged in essential features from their earliest appearance in the Permian to the present day. With the present understanding of the group, this family, as evinced by the structure and development of the corona (as shown in Lovén's figures), is the simplest, least differentiated member of the Echini excepting *Bothriocidaris*.



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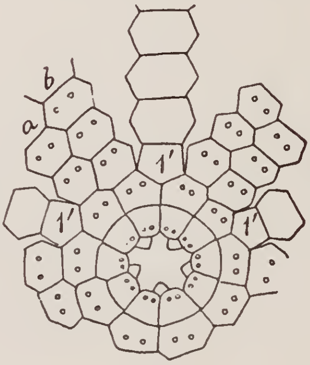

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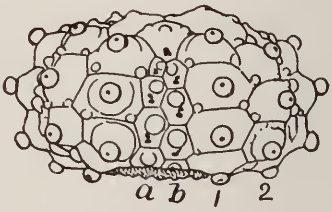

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FIGURE 3.—*Young Goniocidaris canaliculata, A. Ag., after Lovén* (27). Magnified 27 diameters

FIGURE 4.—*Adult Bothriocidaris pahleni, Schmidt, after Schmidt* (37).†

FIGURE 5.—*Side view of young Goniocidaris, the same as figure 3.*

a, *b*, columns of ambulacral plates; 1′, first formed interambulacral plate; 1, 2, further added plates and columns of the interambulacra.

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* Except *Tiarechinus*, which has 3 plates in the second row.

† This figure is a combination of his figures 1*a* and 1*c*.

After the initial interambulacral plate 1′ (figures 3 and 4), in the further development of the interambulacrum we have more plates built, and in all echinoids above *Bothriocidaris* more columns as well. The number of columns acquired varies within wide limits, from 2 in *Cidaris* to 11 in *Lepidechinus rarispinus*, but the extent to which new columns are added in the *Palæechinoidea* varies very much in different types, as shown in the table, facing page 242.

The early stage in which we find a single interambulacral plate, together with two ambulacral plates, in each area is so important that it is desirable to give it a name, the protechinus[*] stage. The protechinus is an early stage in developing Echini, belonging to the phylembryonic[†] period, in which the essential features of the echinoid structure are first evinced. It is a period in the developing young in which we find the ambulacral areas consisting of 2 vertical columns of plates, the interambulacra consisting of a single plate, and in so far representing a single column of plates. This stage is known in the young of *Goniocidaris* (figure 3, page 234), *Strongylocentrotus* (plate 3, figure 8), *Echinus*, Spatangoids and Clypeastroids, *Oligoporus*[‡] (plate 6, figure 26), *Melonites* (plate 3, figures 10, 11), *Pholidocidaris* (plate 9, figure 54) and *Lepidechinus* (plate 7, figure 42). This stage finds its adult representative in *Bothriocidaris* (figure 4, page 234), which has 2 columns of ambulacral and 1 of interambulacral plates in each area throughout life.

This protechinoid stage of echinoderms is comparable as a stage in growth to a similar stage which is expressed in the protegulum of brachiopods, the protoconch of cephalous mollusks, the prodissoconch of pelecypods, and the protaspis of trilobites.

The next stage in growth is marked by the introduction of the second row of interambulacral plates. In all forms above *Bothriocidaris* this stage has 2 plates in each interambulacrum succeeding the first initial plate, excepting *Tiarechinus*, which has 3 plates. This period is still generalized, and does not indicate to which great group of Echini the developing young belongs, excepting in so far as it excludes *Bothriocidaris*

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[*] From πρωτος, primitive, and εχι'νος, echinus. This name comes rather close to *Protoechinus*, which was given as a generic name by Austin. His genus is, however, included by Dr Duncan (9) as a synonym of *Palæechinus*, so that it is not likely to be used in future; also, the name of a stage and a genus need not be confused, for from the context the identity would be clear, and the stage name would, moreover, be spelt with a small letter instead of a capital.

[†] The phylembryo is a name given by Jackson to an early period in development, yet having characters which render the embryo referable to the class or phylum to which it properly belongs. Robert Tracy Jackson: Phylogeny of the Pelecypoda, Mem. Bost. Soc. Nat. Hist., vol. iv, no. viii, 1890.

[‡] In *Oligoporus* and *Melonites* the initial single plate is known only from angles for its reception (see pp. 144 and 192); also in *Melonites* this early stage is complicated by the accelerated development of the ambulacra, for instead of 2 columns, 4 columns exist at the protechinus stage (plate 3, figure 11).

and *Tiarechinus*. When the third row of interambulacral plates develop, if it still has 2 plates, then the developing young belongs to the order Euechinoida, but if it has 3 plates in this row, then the young Echinoderm is a member of the order Perischoechinoida. During further development of both ambulacra and interambulacra in the Perischoechinoida we get progressively added those features which differentiate the genera and species of the families, as has been traced in detail in preceding pages.

The way in which the development of the ambulacrum may be made use of in tracing the morphological and phylogenetic relations of genera is shown under the discussion of *Oligoporus*, where it is shown in the text and by the diagram (figure 1, page 191) that the several genera of the Melonitidæ may be placed in a natural sequence by the characters evinced in the structure of the plates of the ambulacral areas at the ventral border and the ambitus.

In regard to the use of the interambulacral development, its first columns built, numbers 1, 2, 3 and 4, are important as structurally diagnosing the larger divisions of the Echini to which the animal belongs. After the fourth, the addition of other columns is chiefly of value as aiding in the proper systematic placing of species in the genus, for species with a higher number of columns have evidently passed through stages represented by the adults of species with a lower number of columns, whence those species with more columns are further removed in the line of development from the parent stock.* This use of progressive increase in the number of columns is illustrated in the arrangement of species of Melonitidæ and other genera in the table facing page 242.

In Paleozoic Echini the part which the peristome has played in its encroachment on the corona by resorption or the absence of this encroachment is an important character. In embryos of modern Echini, according to Lovén, and in the genus *Bothriocidaris*, the ventral border of the corona is intact. From this condition, which we will call primitive, we get various departures. In the principal series of Paleozoic Echini which advance in the regular line of variation of the group without aberrant specializations we find a greater or less amount of resorption. These groups are the Melonitidæ, which have apparently one row of plates resorbed (*Melonites*, plate 2, figure 2, *Oligoporus* plate 6, figure 25); the Archæocidaridæ, which have several rows of plates resorbed (*Archæocidaris*, plate 8, figures 43 to 45), and Cidarids (plate 8, figure 47), which also have several rows of plates resorbed. In the aberrant groups of Paleozoic Echini which are not in the regular line of variation of the group we get

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*Of course this should not be taken to mean that all species with a smaller number of columns are the ancestors of species with a higher number; they may or may not have been; but what it does mean is that these species are by this means systematically located as more or less advanced in the special line of variation of the genus.

either no or very slight resorption of the corona, and this is the more striking as the several groups are widely separated. These groups are characterized by imbricating plates (except *Tiarechinus*, in which plates are not imbricated). The groups of Palæechini which have no or very slight resorption of the corona are the Cystocidaroida (*Echinocystites*, figured by Thomson (39)), the Plesiocidaroida (*Tiarechinus*, see figures by Lovén (26)), the Lepidocentridæ (*Lepidechinus*, plate 7, figure 42) and the Lepidesthidæ (*Pholidocidaris*, plate 9, figure 54); compare with table facing page 242. These several groups of echinoids are irregular in being specialized in several aberrant characters as compared with their nearest normal allies. The group of the Paleozoic Echini, therefore, seems to present 3 natural divisions as regards relations to the peristome: primitive, with no resorption (*Bothriocidaris*); progressive, with more or less resorption, and aberrant, with no or very slight resorption* (see page 144).

Imbrication of coronal plates is a feature which appears as a character in several groups of Paleozoic echinoids. It is seen well developed in the Lepidocentridæ, the Lepidesthidæ, and the Cystocidaroida among the Palæechinoidea.† Appearing in such widely separated types, it appears that imbrication is a variation built up on independent lines.

All the genera of the Palæechinoidea, as far as known, start with a single plate at the ventral border of the interambulacrum, and above *Bothriocidaris* all increase to several (*Tiarechinus*) or many columns in the adult. None of these types show evidence of a return from a many column to a few column type except in so far as indicated in the early dropping out of the fourth column in *Lepidesthes wortheni* (plate 9, figure 53), and as slightly indicated in the dropping out of the eleventh column near the dorsal border in *Melonites giganteus* (plate 5, figure 21), and the brief period of existence of the sixth column in *Oligoporous missouriensis* (plate 9, figure 50). They all, therefore, apparently culminate in these extreme forms.

The Euechinoidea as representedby *Cidaris* (page 234), in the development of the corona show strong evidence in both ambulacral and interambulacral areas, pointing toward *Bothriocidaris* as a parent form. In the Upper Silurian and Devonian we know only a few aberrant types, so that we must suppose that intermediate forms between the primitive *Bothriocidaris* and the several derivative types are at present quite unknown. *Tetracidaris* in the Cretaceous has 4 columns of plates in the lower part

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* Of the Exocyclica in the subclass Euechinoidea we have no Paleozoic representatives. This group as a whole is characterized by retaining in the adult the single initial plates of the interambulacral areas, as in aberrant types of Palæechinoidea, see numerous figures by A. Agassiz (3), Lovén (25), Clark (6) and others. In this group, the Exocyclica, also we have specialized features, as bilateral symmetry, an eccentric periproct and peculiarities in the form and arrangement of plates and spines not seen in regular forms (Endocyclica) of its subclass.

† Imbrication is also a feature of the Cretaceous and Recent family, the Echinothuridæ in the Euechinoidea.

of the corona, and in later growth these drop out to 2 columns. This looks like a derivation from some Paleozoic form with many columns of interambulacral plates, but the genus is so little known that any conclusions with present knowledge would be hazardous.

Mr Agassiz, in his " Revision of the Echini," page 645, in writing of the Paleozoic Echini, says: " No writer thus far has as yet succeeded in homologizing these Echini with our recent Echini; the structure of the ambulacral and interambulacral system finding no parallel apparently in any of the recent Echini." Further on, at page 650, he says of the Paleozoic Echini: " We know nothing as yet of the mode of formation of the additional rows of plates either in the ambulacral or interambulacral system; this would throw great light on the homologies of this suborder." It is hoped that the present contribution may be accepted as solving some of the difficulties. A study of young specimens is most important for a positive statement in regard to the changes passed through in the ontogeny of the individual, which has here been traced by stages in nearly or quite adult specimens. Such young specimens I have been unable to secure, and they must be extremely rare, if ever found.

A PROPOSED NEW CLASSIFICATION OF PALEOZOIC ECHINI, WITH A SYSTEMATIC TABLE OF THE SEVERAL GROUPS.

Basis of the classification.—From the results of preceding studies it is felt that a natural systematic classification of Paleozoic Echini can be based on the features of the anatomy and development of the ambulacrum and interambulacrum and the relations of the peristome to the ventral border of the corona. While these features are the main ones, others are considered in the minor divisions of the group, such as imbrication of plates, the form of the plates and the position of ambulacral pores.

This classification, which is presented in tabular form, is distinctly intended as a systematic arrangment, in which the species, genera, families and orders are arranged so as to express their structural relations in a natural order. It is not intended as a phylogenetic table. While the phylogeny would probably follow somewhat similar lines, there are so many great gaps that it could not be stated that this is the true genealogical history of the group. In the table details of structure are given for each division from class to species, so that in this consideration of the table only additional and general features will be discussed.

Subclass Palæechinoidea—Order I, Bothriocidaroida.—The simplest known member of the Paleozoic Echini is the genus *Bothriocidaris*, as discussed in previous pages. Its order should therefore form the first division of its subclass. The two species known have essentially the same characters.

Subclass Euechinoidea.—The class Echinoidea is divided into two subclasses—one, which is limited to the Paleozoic, except for the Triassic genus *Tiarechinus*, and the other, which is known from the Permian to the present time. On the accepted bases of classification this second class, the Euechinoidea, in its simplest members, as represented by *Cidaris*, is nearest to the primitive, as expressed in the embryo and the genus *Bothriocidaris*, of any member of the group. The Euechinoidea are represented, as at present known in the Paleozoic, only by a few species of the genus *Cidaris;* therefore no further consideration is given to this group.

Subclass Palæechinoidea—Order II, Perischoechinoida.—In its normal types this order presents a distinct, continuous series, varying in the line of progressive addition of columns of interambulacral or ambulacral and interambulacral plates, with a greater or less resorption of the corona by encroachment of the peristome.

Melonitidæ.—Ambulacral areas, as stated, are considered the most important structural features; therefore as the family Melonitidæ have the greatest advance in the line of progressive complication of this part, they are considered the most highly evolved group of the Paleozoic Echini. In considering this family careful attention is called to the diagram, figure 1, page 191.

Rhoechinus (see figure 1, page 191, and plate 7, figures 36, 37 and 40) is the simplest genus of the family, having but 2 columns of ambulacral plates in each area. The simplest species has 4 columns of interambulacral plates, and the most highly specialized species has 8. This highest species, *R. gracilis* (plate 7, figure 36), in area *C* has a ninth column near the dorsal area, but as it originated so late and in only one area we should not call it a character of the species unless found in other specimens.

Palæechinus (see figure 1, page 191, and plate 7, figures 38, 39) is further specialized than *Rhoechinus*, having the beginning of that condition of multiplication of ambulacral plates which is characteristic of the family (see diagram, page 191). We cannot say that there are 2 columns of plates in the ambulacrum, and neither should we like to call it 4; therefore in the table the ambulacral columns are expressed as 2+. The simplest species has 5 columns of interambulacral plates, and the most specialized species has from 6 to 7 in each area.

Oligoporus (see figure 1, page 191, and plate 6, figures 25–34, and plate 9, figures 50–52) is the third genus in the family and is quite well known from a considerable amount of good material. The ambulacra ventrally consist of 2 columns of plates, which pass into 4 columns in the adult*

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* In *Oligoporus danæ* (plate 6, figure 30) there are a few additional plates in the middle of each half ambulacrum.

by a process of drawing out (page 189). The simplest species has 4 columns of interambulacral plates and the highest species has 9 columns, with a large number of species which are progressively intermediate in structure.

Melonites (see figure 1, page 164; plate 2, plate 3, figures 10–17, plates 4 and 5) is the best known of all Paleozoic genera, one species, *M. multiporus*, Norw. and Owen, being abundantly represented. It is the study of this genus that gave the key to the present classification. This genus is the most highly differentiated in the direct line of progressive development of both ambulacra and interambulacra of any of the Paleozoic Echini.* The ambulacra have ventrally 4 columns of plates (see page 140), which are comparable anatomically and morphologically to the 4 columns of adult *Oligoporus* (figure 1, page 191). During development new columns of plates are introduced between the lateral and median columns of each half ambulacrum (plate 2, figure 4), until the full complement of the species is attained. The species *M. dispar*, (Fischer), has 6 columns of ambulacral plates, and on this basis, as well as having the least number, 4, of interambulacral plates, is the simplest species of the genus. In its adult it represents a very early stage in the development of higher species (plate 2, figure 2, and plate 5, figure 21). The two species, *M. indianensis*, Miller and Gurley, and *M. septenarius*, Whitfield, have each 8 columns of ambulacral plates in the adult. The latter species has 7 columns of interambulacral plates (plate 9, figure 49), and is therefore considered the more specialized of the two. The next species, *M. crassus*, Hambach, has 10 columns of ambulacral and 5 of interambulacral plates. As the ambulacra are considered the more important character, this species is placed above *M. septenarius*, although that species has 2 more columns of interambulacral plates. *M. irregularis*, Hambach, has from 6 to 10 columns of ambulacral and from 5 to 7 of interambulacral plates.† The next species, *M. multiporus*, Norw. and Owen, which is the most abundant of all Paleozoic echinoids, has 10 columns of ambulacral plates and 7, 8 or 9 columns of interambulacral plates. This variation is seen in different individuals and even in different areas of the same individual (see tables, pages 165 to 170). *Melonites giganteus*, Jackson, has 12 columns of ambulacral and 11 of interambulacral plates (plate 4, figure 19, and plate 5, figures 21–24). The next species, *M. etheridgii*, W. Keeping (21), from an estimate made by that author, has 12 or 14 columns of

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* *Lepidocentrus* and *Lepidechinus* each in one species have 11 columns of interambulacral plates, so that in this single feature they equal the highest species of the Melonitidæ. *Lepidesthes colletti* surpassed any species of *Melonites* in having 18 or perhaps 20 (?) columns of ambulacral plates.

† This description is indefinite. It may be meant to read that the smaller number is at the ventral portion and the higher number at the ambitus, or further dorsally, which would be in accordance with the condition seen in the structure of other species.

ambulacral plates and probably 9 columns of interambulacrals. As this species, *M. etheridgii*, has up to 14 columns of plates, it is by our accepted standard the most specialized species of the genus.

Lepidesthidæ.—This family is characterized by 6 or more columns of ambulacral plates, which associate it systematically near to the Melonitidæ; it differs from the Melonitidæ in having imbricated plates and pores in the center of ambulacral plates.

Lepidesthes wortheni (plate 9, figure 53), the simplest species, has 4 columns of ambulacral plates ventrally, as in *Melonites;* they increase to 7 or 8 columns at the ambitus. In the interambulacra there are 4 columns of plates ventrally, decreasing to 3 at the ambitus. In another specimen there are 3 columns throughout the length of these areas (page 208). Another species, *L. formosus*, Miller, has 8 ambulacral and 5 interambulacral columns. The next species, *L. spectabilis*,* has 10 ambulacral columns, as has also the third species, *L. coreyi*, M. and W. The most specialized species, *L. colletti*, White, in regard to ambulacral development is the most specialized of all Paleozoic Echini, having many more columns than any other known species.

Pholidocidaris (see plate 9, figure 54) is a very distinct genus on account of the peculiarities of its ambulacral plates and the irregularity and strong imbrication of both ambulacral and interambulacral plates. Better material in this genus is much to be desired. The two species, *P. irregularis*, M. and W. and *meeki*, Jackson, are about on a par as regards differentiation of structure.

Archæocidaridæ.—*Archæocidaris* (plate 8, figures 43–46) as a genus is not characterized by a great development of interambulacral plates and has only 2 columns of ambulacrals. One striking feature is the extensive resorption of the ventral border of the corona by the encroachment of the peristome, as shown by *A. wortheni.* Many species have been described from dissociated spines and plates, but obviously they are wanting in those characters which would enable one to include them in a classification based on a required knowledge of a more or less complete corona. *Archæocidaris wortheni*, Hall, has 4 columns of interambulacral plates. *A. drydenensis*, Vanuxem has 7 columns of interambulacral plates, and is therefore placed above as being more specialized.

Lepidocidaris (see plate 7, figure 41) in the sum of its characters is placed close to *Archæocidaris*, but it has more than 2 columns of ambulacral plates. These additional plates were apparently formed by a drawing-out process, as in *Oligoporus* (compare plate 7, figure 41 and plate 6, figure 25).

Lepidocentridæ.—This family is systematically nearest to the Archæ-

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*This species was described as *Hyboechinus spectabilis.* See statement, page 207.

ocidaridæ, but has essential differences in the strongly imbricated character and also unusual form of interambulacral plates. Another difference of significance is the small peristome and the correlated retention of the initial interambulacral plate in the adult (*Lepidechinus*, plate 7, figure 42).

Lepidocentrus (see figure 2, page 223) is considered the central type because its interambulacral plates, though specialized in form, are nearest the usual form of plates seen in normal types, especially the young, recently added plates at the dorsal portion of the corona (see *Melonites*, plate 3, figure 13). *L. rhenanus*, Beyrich is considered the least specialized species, because its interambulacral plates are nearly hexagonal and therefore show less modification from normal types than the other species of the genus. It is also simpler in having fewer columns of interambulacral plates than the next species. *L. mülleri*, Schultze has 11 columns of interambulacral plates, and its plates are quite near to rhombic in form throughout the entire test.

Lepidechinus (see plate 7, figure 42) is a genus quite distinct from *Lepidocentrus*, but only one species, *L. rarispinus*, Hall, is at all well known. This species has strongly imbricated plates. The initial interambulacral plate is retained in the adult and it has a highly accelerated development. In the table the species *L. imbricatus*, Hall is put first because as described it has fewer columns of interambulacral plates than *L. rarispinus.*

Perischodomus (see Keeping (22)) differs essentially in the form of its plates from other genera of the family, the plates being more nearly hexagonal than in other genera. The species from this country, *P. illinoisensis*, is not well known.

Order III, Cystocidaroida.—This order is represented by the genus *Echinocystites*, Wyv. Thomson (39). It is unsatisfactory to locate systematically on account of conflicting evidence. In the table, therefore, the order is given, but without descriptive detail. This is done because, while not wishing to omit altogether so important a group as a whole order of Paleozoic Echini, I was unwilling to introduce confusion by giving details of structure which were apparently out of place in the systematic scheme. The details of structure are given at this place.

(Eu.) *E. pomum*, Wyv. Thomson, 4 A., 8 I.

(Eu.) *E. uva*, Wyv. Thomson, 4 A., 6 I.
|
Echinocystites, Wyv. Thomson, 4 A., 6–8 I.
| Upper Silurian.
Order III. CYSTOCIDAROIDA, 4 A., numerous I. Peristome small,
periproct eccentric. Plates imbricated.

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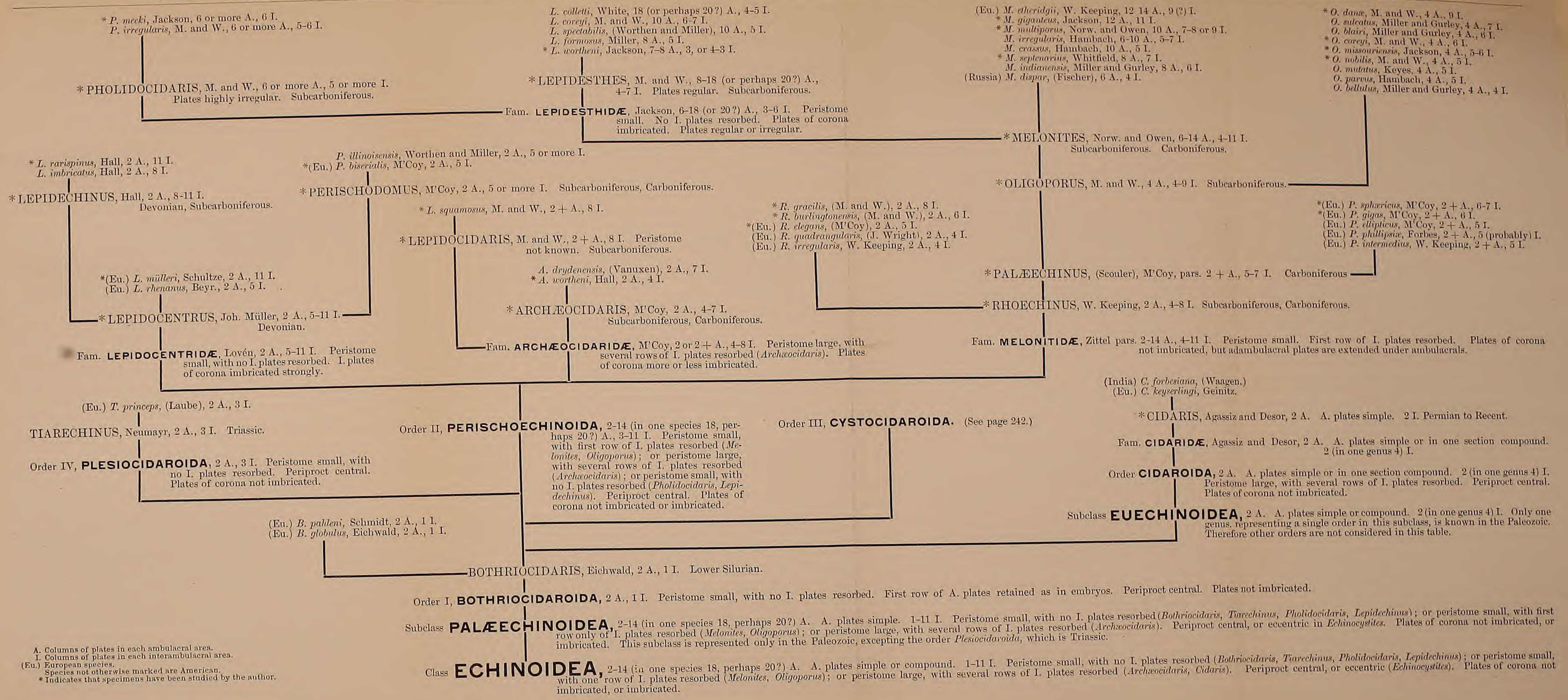
Systematic Classification of Paleozoic Echini, including one Triassic Genus, based on the Structure and Growth of the Ambulacra and Interambulacra, and the Peristome.



* *P. meeki*, Jackson, 6 or more A., 6 I.
P. irregularis, M. and W., 6 or more A., 5-6 I.

* PHOLIDOCIDARIS, M. and W., 6 or more A., 5 or more I. Plates highly irregular. Subcarboniferous.

L. colletti, White, 18 (or perhaps 20?) A., 4-5 I.
L. coreyi, M. and W., 10 A., 6-7 I.
L. spectabilis, (Worthen and Miller), 10 A., 5 I.
L. formosus, Miller, 8 A., 5 I.
* *L. wortheni*, Jackson, 7-8 A., 3, or 4-3 I.

* LEPIDESTHES, M. and W., 8-18 (or perhaps 20?) A., 4-7 I. Plates regular. Subcarboniferous.

Fam. **LEPIDESTHIDÆ**, Jackson, 6-18 (or 20?) A., 3-6 I. Peristome small. No I. plates resorbed. Plates of corona imbricated. Plates regular or irregular.

(Eu.) *M. etheridgii*, W. Keeping, 12 14 A., 9 (?) I.
* *M. giganteus*, Jackson, 12 A., 11 I.
* *M. multiporus*, Norw. and Owen, 10 A., 7-8 or 9 I.
M. irregularis, Hambach, 6-10 A., 5-7 I.
M. crassus, Hambach, 10 A., 5 I.
* *M. septenarius*, Whitfield, 8 A., 7 I.
M. indianensis, Miller and Gurley, 8 A., 6 I.
(Russia) *M. dispar*, (Fischer), 6 A., 4 I.

* MELONITES, Norw. and Owen, 6-14 A., 4-11 I. Subcarboniferous. Carboniferous.

* *O. danæ*, M. and W., 4 A., 9 I.
O. sulcatus, Miller and Gurley, 4 A., 7 I.
O. blairi, Miller and Gurley, 4 A., 6 I.
* *O. coreyi*, M. and W., 4 A., 6 I.
* *O. missouriensis*, Jackson, 4 A., 5-6 I.
* *O. nobilis*, M. and W., 4 A., 5 I.
O. mutatus, Keyes, 4 A., 5 I.
O. parvus, Hambach, 4 A., 5 I.
O. bellulus, Miller and Gurley, 4 A., 4 I.

* OLIGOPORUS, M. and W., 4 A., 4-9 I. Subcarboniferous.

* *L. rarispinus*, Hall, 2 A., 11 I.
L. imbricatus, Hall, 2 A., 8 I.

* LEPIDECHINUS, Hall, 2 A., 8-11 I. Devonian, Subcarboniferous.

P. illinoisensis, Worthen and Miller, 2 A., 5 or more I.
*(Eu.) *P. biserialis*, M'Coy, 2 A., 5 I.

* PERISCHODOMUS, M'Coy, 2 A., 5 or more I. Subcarboniferous, Carboniferous.

*(Eu.) *L. mülleri*, Schultze, 2 A., 11 I.
(Eu.) *L. rhenanus*, Beyr., 2 A., 5 I.

* LEPIDOCENTRUS, Joh. Müller, 2 A., 5-11 I. Devonian.

Fam. **LEPIDOCENTRIDÆ**, Lovén, 2 A., 5-11 I. Peristome small, with no I. plates resorbed. I. plates of corona imbricated strongly.

* *L. squamosus*, M. and W., 2 + A., 8 I.

* LEPIDOCIDARIS, M. and W., 2 + A., 8 I. Peristome not known. Subcarboniferous.

A. drydenensis, (Vanuxen), 2 A., 7 I.
* *A. wortheni*, Hall, 2 A., 4 I.

* ARCHÆOCIDARIS, M'Coy, 2 A., 4-7 I. Subcarboniferous, Carboniferous.

Fam. **ARCHÆOCIDARIDÆ**, M'Coy, 2 or 2 + A., 4-8 I. Peristome large, with several rows of I. plates resorbed (*Archæocidaris*). Plates of corona more or less imbricated.

* *R. gracilis*, (M. and W.), 2 A., 8 I.
* *R. burlingtonensis*, (M. and W.), 2 A., 6 I.
*(Eu.) *R. elegans*, (M'Coy), 2 A., 5 I.
(Eu.) *R. quadrangularis*, (J. Wright), 2 A., 4 I.
(Eu.) *R. irregularis*, W. Keeping, 2 A., 4 I.

*(Eu.) *P. sphæricus*, M'Coy, 2 + A., 6-7 I.
*(Eu.) *P. gigas*, M'Coy, 2 + A., 6 I.
(Eu.) *P. ellipticus*, M'Coy, 2 + A., 5 I.
(Eu.) *P. phillipsiæ*, Forbes, 2 + A., 5 (probably) I.
(Eu.) *P. intermedius*, W. Keeping, 2 + A., 5 I.

* PALÆECHINUS, (Scouler), M'Coy, pars. 2 + A., 5-7 I. Carboniferous

* RHOECHINUS, W. Keeping, 2 A., 4-8 I. Subcarboniferous, Carboniferous.

Fam. **MELONITIDÆ**, Zittel pars. 2-14 A., 4-11 I. Peristome small. First row of I. plates resorbed. Plates of corona not imbricated, but adambulacral plates are extended under ambulacrals.

(Eu.) *T. princeps*, (Laube), 2 A., 3 I.

TIARECHINUS, Neumayr, 2 A., 3 I. Triassic.

Order IV, **PLESIOCIDAROIDA**, 2 A., 3 I. Peristome small, with no I. plates resorbed. Periproct central. Plates of corona not imbricated.

Order II, **PERISCHOECHINOIDA**, 2-14 (in one species 18, perhaps 20?) A., 3-11 I. Peristome small, with first row of I. plates resorbed (*Melonites*, *Oligoporus*); or peristome large, with several rows of I. plates resorbed (*Archæocidaris*); or peristome small, with no I. plates resorbed (*Pholidocidaris*, *Lepidechinus*). Periproct central. Plates of corona not imbricated or imbricated.

Order III, **CYSTOCIDAROIDA.** (See page 242.)

(India) *C. forbesiana*, (Waagen.)
(Eu.) *C. keyserlingi*, Geinitz.

* CIDARIS, Agassiz and Desor, 2 A. A. plates simple. 2 I. Permian to Recent.

Fam. **CIDARIDÆ**, Agassiz and Desor, 2 A. A. plates simple or in one section compound. 2 (in one genus 4) I.

Order **CIDAROIDA**, 2 A. A. plates simple or in one section compound. 2 (in one genus 4) I. Peristome large, with several rows of I. plates resorbed. Periproct central. Plates of corona not imbricated.

Subclass **EUECHINOIDEA**, 2 A. A. plates simple or compound. 2 (in one genus 4) I. Only one genus, representing a single order in this subclass, is known in the Paleozoic. Therefore other orders are not considered in this table.

(Eu.) *B. pahleni*, Schmidt, 2 A., 1 I.
(Eu.) *B. globulus*, Eichwald, 2 A., 1 I.

BOTHRIOCIDARIS, Eichwald, 2 A., 1 I. Lower Silurian.

Order I, **BOTHRIOCIDAROIDA**, 2 A., 1 I. Peristome small, with no I. plates resorbed. First row of A. plates retained as in embryos. Periproct central. Plates not imbricated.

Subclass **PALÆECHINOIDEA**, 2-14 (in one species 18, perhaps 20?) A. A. plates simple. 1-11 I. Peristome small, with no I. plates resorbed (*Bothriocidaris*, *Tiarechinus*, *Pholidocidaris*, *Lepidechinus*); or peristome small, with first row only of I. plates resorbed (*Melonites*, *Oligoporus*); or peristome large, with several rows of I. plates resorbed (*Archæocidaris*). Periproct central, or eccentric in *Echinocystites*. Plates of corona not imbricated, or imbricated. This subclass is represented only in the Paleozoic, excepting the order *Plesiocidaroida*, which is Triassic.

Class **ECHINOIDEA**, 2-14 (in one species 18, perhaps 20?) A. A. plates simple or compound. 1-11 I. Peristome small, with no I. plates resorbed (*Bothriocidaris*, *Tiarechinus*, *Pholidocidaris*, *Lepidechinus*); or peristome small, with one row of I. plates resorbed (*Melonites*, *Oligoporus*); or peristome large, with several rows of I. plates resorbed (*Archæocidaris*, *Cidaris*). Periproct central, or eccentric (*Echinocystites*). Plates of corona not imbricated, or imbricated.

A. Columns of plates in each ambulacral area.
I. Columns of plates in each interambulacral area.
(Eu.) European species.
Species not otherwise marked are American.
* Indicates that specimens have been studied by the author.

The 4 columns of ambulacral plates of *Echinocystites* would on our accepted basis of classification associate this type with *Oligoporus* as the only other type known which has such a structure; but the fact that the genus occurs in the Upper Silurian is very strong evidence against such association. The interambulacra have few columns of plates at the ventral area, as shown in the published figures, and proceeding dorsally new columns are introduced until the full number is attained. The imbrication of the plates and eccentric anal area, together with the small peristome which is gathered from Sir Wyville Thomson's figures and description, would indicate that this type is aberrant, for we know these features, particularly when in association, only in aberrant forms. On the whole evidence it seems much the safer course to leave this order by itself rather than place it near forms which have apparently similar ambulacral detail. To place it near *Oligoporus* would on the evidence be a blind following of system.

Order IV, Plesiocidaroida.—This order, which is the last group to be considered, is represented only by the one Triassic genus, *Tiarechinus*. This type has been fully illustrated by Professor Lovén (26). In its structural detail this form differs from all the Perischoechinoida and therefore naturally forms a separate order by itself. The most important character of this type is the fact that, while it has a single interambulacral plate in the first row of the corona like other echinoids, in the second row it has 3 plates. All other types above *Bothriocidaris*, as far as known, have 2 plates in the second row, and the existence of 3 in *Tiarechinus* is therefore to be looked at as a feature standing quite by itself as a structural detail. After the second row, no more interambulacral plates are added in *Tiarechinus*.

The accompanying table includes all genera of Paleozoic Echini except *Xenocidaris*, which is known only from spines (page 222), *Spatangopsis*,* *Koninckocidaris*,* and *Echinodiscus*,† which are imperfectly known. Of the genera tabulated all the species are included excepting species which have been described from dissociated spines and plates or fragmentary specimens, which with present knowledge are wanting in the characters for proper systematic interpolation. The known species of the included genera which are omitted in the table are *Lepidocentrus eifelianus* and quite a large number of species of *Archæocidaris*. In the table the numbers of the orders and the spelling of class and ordinal names are adopted from Dr Duncan's "Revision of the Genera and Great Groups of the Echinoidea."

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* Which have not been figured and are not sufficiently understood to be included.

† Worthen and Miller (42). Two species are ascribed to this genus.

List of Publications quoted or referred to in the Text.

In this list all papers relate to echinoderms more or less exclusively. The few papers referred to in the text which do not deal with them are included in foot-notes. In the text, numbers in parentheses referring to this list are appended to references. The present list, with additional references cited by Keyes (24), Lovén (25) and Zittel (44), makes a quite complete bibliography of Paleozoic Echini.

1. Alexander Agassiz: Revision of the Echini. *Mem. Mus. Comp. Zoöl.*, vol. iii, 1872–'74. (This memoir contains a bibliography.)
2. Alexander Agassiz: Palæontological and Embryological Development. *Proc. Am. Assoc. Adv. Science*, 1880.
3. Alexander Agassiz: Report on the Echinoida. *Challenger Reports, Zoölogy*, vol. iii, 1881.
4. Alexander Agassiz: Calamocrinus diomedæ, with notes on the apical system and the homologies of Echinoderms. *Mem. Mus. Comp. Zoöl.*, vol. xvii, no. 2, 1892.
5. W. H. Bailey: Notes on the structure of *Palæechinus*. *Journ. Roy. Geol. Soc. Ireland*, 1865.
6. William Bullock Clark: The Mesozoic Echinodermata of the United States. *Bull. U. S. Geol. Surv.*, no. 97. Washington, 1893. (This memoir contains a bibliography of the subject treated.)
7. Dollo and Buisseret: Sur quelques Paléchinides. *Comtes Rendus Acad. des Sciences*, T. 106, p. 958, 1888.
8. P. Martin Duncan: On some points in the anatomy of the species of *Palæechinus*, (Scouler) M'Coy, and a proposed classification. *Ann. and Mag. Nat. Hist.*, ser. 6, vol. iii, 1889.
9. P. Martin Duncan: A revision of the genera and great groups of the Echinoidea. *Journ. Linnean Soc.*, vol. xxiii, 1889.
10. Duncan and Sladen: Tertiary and Upper Cretaceous fauna of Western India. *Mem. Geol. Surv. India, Palæont. Indica*, ser. xiv, vol. i. Calcutta.
11. R. Etheridge: Echinothuridæ and Perischoechinidæ. *Quart. Journ. Geol. Soc. London*, vol. xxx, pp. 307–316, 1874.
12. G. Fischer von Waldheim: *Bull. de la Soc. Imp. des Naturalistes de Moscou*, vol. xxi, 1848. (Describes *Melonites dispar*, (Fischer).)
13. E. Forbes: *Mem. Geol. Sur. Great Britain and Mus. Practical Geol.*, vol. ii, part 1, p. 384. (Describes *Palæechinus phillipsiæ*.)
14. H. B. Geinitz: Die Versteinerungen des Zechsteingebirges und Rothliegenden oder des Permischen Systemes in Sachsen, 1848. (Describes *Cidaris keyserlingi*, Geinitz.)
15. James Hall: Geological Survey of Iowa, vol. 1, part ii, 1858.
16. James Hall: Descriptions of new species of Crinoidea from investigations of the Iowa Geological Survey. Preliminary notice. Albany, February 25, 1861. (Describes *Lepidechinus imbricatus*, genus and sp. nov.)
17. James Hall: *Twentieth Annual Report New York State Cabinet Nat. Hist.*, 1867. (Describes *Lepidechinus rarispinus*, Hall, and *Archæocidaris drydenensis*, (Vanuxem).)

18. G. Hambach: Description of new species of Paleozoic Echinodermata. *Trans. St. Louis Acad. Sc.*, vol. iv, 1878–'86, p. 548.

19. Robert T. Jackson: Studies of *Oligoporus* (abstract of a paper read). *Science*, new series, vol. ii, November 22, 1895.

20. Otto Jaekel: Ueber die alteste Echiniden-Gattung Bothriocidaris. *Sitzungs-Ber. Gesellsch. Naturforsch. Freunde*, Berlin, Jahrg, 1894.

21. W. Keeping: On the discovery of *Melonites* in Britain. *Quart. Journ. Geol. Soc., London*, vol. 32, 1876.

22. W. Keeping: Notes on the Paleozoic Echini. *Quart. Journ. Geol. Soc., London*, vol. 32, 1876. (New facts about *Perischodomus*, and describes *Rhoechinus irregularis*, genus and species nov.)

23. C. R. Keyes: Geol. Surv. Missouri, vol. iv, 1894.

24. C. R. Keyes: Synopsis of American Paleozoic Echinoids. *Proc. Iowa Acad. Sc. for 1894*, vol. ii. (This paper contains very complete references to publications on American Paleozoic Echini.)

25. Sven Lovén: Études sur les Echinoidées. *Kongl. Svensk. Vetenskaps-Akad., Handl.*, B. 11. Stockholm, 1872. (Contains numerous references to publications on Paleozoic Echini.)

26. Sven Lovén: On Pourtalesia. *Kongl. Svensk. Vetenskaps-Akad., Handl.*, B. 19. Stockholm, 1883.

27. Sven Lovén: Echinologica. *Bihang till Kongl. Svensk. Vetenskaps-Akad., Handl.*, B. 18: iv. Stockholm, 1892.

28. F. M'Coy: Synopsis of the Carboniferous limestone fossils of Ireland, 1844. (Describes species of *Archæocidaris* and *Palæechinus*.)

29. F. M'Coy: (Paleozoic Echinodermata) in *Contributions of British Palæontology*, 1854.

30. Meek and Worthen: Geological Survey of Illinois, vol. ii, 1866.

31. Meek and Worthen: Geological Survey of Illinois, vol. v, 1873.

32. Meek and Worthen: Proceedings of the Academy of Natural Science, Philadelphia, vol. xxii, p. 34, 1870. (Describe *Lepidesthes coreyi*.)

33. S. A. Miller: Remarks upon the Kaskaskia group. *Journ. Cinc. Soc. Nat. Hist.*, vol. ii, 1879. (Describes *Lepidesthes formosus*.)

34. Miller and Gurley: Descriptions of some new species of Invertebrates from the Paleozoic rocks of Illinois. *Bull. Illinois State Mus. Nat. Hist.*, no. 3, 1894. (Describe new species of *Melonites*, *Oligoporus* and *Archæocidaris*.)

35. Joh. Müller: Ueber neue Echinodermen des Eifeler Kalkes. *Abhandl. K. Akad. d. Wiss.*, Berlin, 1856. (Describes *Lepidocentrus*.)

36. F. Roemer: Ueber den Bau von Melonites. *Wiegmann's Archiv*, 1855.

37. F. Schmidt: Miscellanea Silurica, ii, p. 36. *Mem. Acad. Imp., St. Petersburg*, vol. xxi, no. 11, 1874. (Describes and figures species of *Bothriocidaris*.)

38. L. Schultze: Monographie der Echinodermen des Eifeler Kalkes, 1866. (Describes *Lepidocentrus* and *Xenocidaris*.)

39. Wyville Thomson: On a new Paleozoic group of Echinodermata. *Edinburgh New Phil. Journ.*, 1861, vol. xiii, p. 106. (Describes *Echinocystites*.)

40. W. Waagen: Salt Range. *Mem. Geol. Surv. India*, ser. xiii, vol. i, part v. (Describes *Cidaris forbesiana*, (Waagen).)

41. C. A. White: Contribution to Invertebrate Paleontology, no. 8. Fossils from the Carboniferous Rocks of the Interior States. *U. S. Geol. and Geog. Surv. Terr.*, 1873, part 1. (Describes *Lepidesthes colletti*, White.)

42. Worthen, St. John and Miller: Geological Survey of Illinois, vol. vii, 1883.
43. Joseph Wright: Description of a new species of *Palæechinus*. *Journ. Royal Geol. Soc., Ireland*, vol. i, part 1, 1865.
44. Karl A. Zittel: Handbuch der Palæontologie.

Explanation of Plates.

In the accompanying figures the radial orientation of specimens, when expressed, is designated by letters placed on the interambulacral and ambulacral areas *A*, *B*, *C*, etcetera, up to *J*, for the 10 areas, as in plate 4, figure 19. The interambulacrum selected as *A* is a matter of indifference, for at present I think there is no means of orienting Palæechini, as in modern regular Echini, by means of the madreporic body. The sequence adopted is that as viewed looking down on the corona from the dorsal side and revolving like the hands of a watch, as in plate 5, figure 20. When viewed from the oral side, as in plate 2, figure 2, the same orientation is preserved, but is of necessity in a reversed order.

The following letters are used to designate plates or series of plates in the figures:

P and *N* = unusual pentagonal plates, seen in a few interambulacral areas.

Terminal pentagonal plates of interambulacral columns as introduced are numbered from 1 upward.

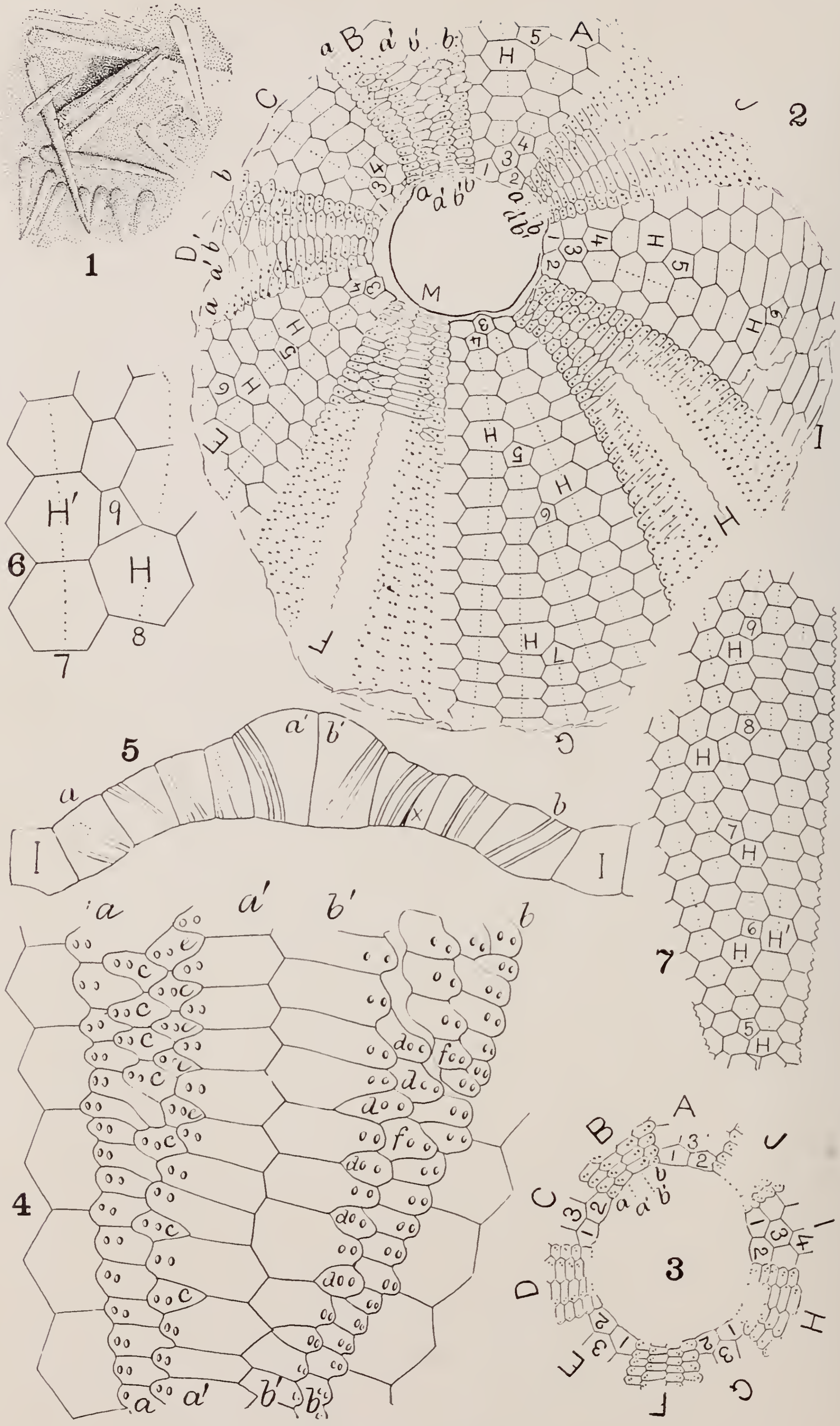
H = heptagonal plates, seen in interambulacral areas, usually adjacent to terminal pentagons.

a, *b* are the two primary ambulacral columns of ambulacral plates.

a′, *b′* are the two derivative ambulacral columns seen in *Oligoporus* (plate 6, figure 25) and *Melonites* (plate 2, figure 4).

All figures except plate 1, figure 1, were drawn by Mr J. H. Emerton. The exceptional figure was drawn by Mr M. Westergren. The photographs from which plate 4 was made were taken by Mr Charles H. Currier, of Boston. The source from which all specimens or figures was derived is given in the description of plates.

In the explanations one or two page references are given to indicate where the principal description of the figure is. Many of the figures, however, are discussed at several other places in the text.



PALEOZOIC ECHINI.

EXPLANATION OF PLATE 2.

FIGURE 1.—*Melonites multiporus*, Norw. and Owen; spines. Specimen in Museum of Comparative Zoölogy, catalogue number 2988. Magnified 6 + diameters. Page 137.

FIGURE 2.—*Melonites multiporus;* viewed from oral end. The 5 ambulacral areas have 4 columns ventrally; 3 interambulacra, *A*, *C* and *I*, have 2 plates ventrally; 2 areas, *E* and *G*, have 3 plates ventrally. *M* = remnant of perignathic girdle. Specimen in Museum of Comparative Zoölogy, catalogue number 3000. Magnified 1½ diameters. Pages 140, 142.

FIGURE 3.—*Melonites multiporus;* ventral border of corona. The ambulacral areas terminate in 4 plates, except area *J*, which is wanting ventrally. The interambulacra terminate ventrally in 2 plates. Specimen in Museum of Comparative Zoölogy, catalogue number 3003. Magnified 1½ diameters. Page 142.

FIGURE 4.—*Melonites multiporus;* development of ambulacrum. The 4 columns at the base, *a*, *a′* and *b′*, *b*, are extended dorsally as the 2 median and 2 outer columns of the area. New columns, *c*, *d*, *e*, *f*, are introduced in the median portion of each half-area. Museum of Comparative Zoölogy, catalogue number 2994. Magnified 4 diameters. Compare figure 1, page 191, and plate 4, figure 18. Page 140.

FIGURE 5.—*Melonites multiporus;* cross-section of ambulacrum; *I*, *I*, adambulacral plates; *a*, *b*, the 2 outer; *a′*, *b′*, the 2 median columns of ambulacral plates. Pores pass from the outer border of the plate on the distal side to the median or inner side of the plate on the proximal side. The dotted portions of the pores are reconstructions, not being shown in the section. Plate *X* does not show the pores in the plane of this section. Specimen in Museum of Comparative Zoölogy, catalogue number 3030. Magnified 2 diameters. Pages 141, 154.

FIGURE 6.—*Melonites multiporus;* showing variation; column 9 originates in a tetragonal instead of a pentagonal plate; 2 adjacent heptagons exist instead of one. Specimen in Museum, of Comparative Zoölogy, catalogue number 3017. (Area *I*, see tabulation, page 169). Magnified 3 diameters. Page 154.

FIGURE 7.—*Melonites multiporus;* interambulacrum, showing variation; the initial plate of column 6 is tetragonal, the heptagon associated with pentagon 8 occurs in the fifth instead of the seventh column, a rare variation. The ninth column at its origin has five columns on the left and three on the right, a very unusual variation (compare with table, page 167). Specimen in Museum of Comparative Zoölogy, catalogue number 3021. Life size. Page 159.

All the specimens on this plate are from the Subcarboniferous, Saint Louis group, Saint Louis, Missouri.

EXPLANATION OF PLATE 3.

FIGURE 8.—*Strongylocentrotus drobachiensis*, (O. F. M.); ventral border of part of corona, showing primary ambulacral plates and succeeding ambulacral plates of corona; also the single initial plate 1′ of the interambulacrum succeeded by 2 plates 1 and 2, in next row. Magnified about 50 diameters. Recent. Page 144.

FIGURE 9.—*Strongylocentrotus drobachiensis;* later stage than figure 8, in which some resorption of ventral border of corona has taken place. Figures 8 and 9 are portions of figures after Lovén (27). Page 144.

FIGURE 10.—*Melonites multiporus;* showing an angle on ventral border of plates 1 and 2 apparently for the initial plate 1′, which is restored in shading. Column 4 is introduced by tetragonal plate 4. Magnified 2 diameters. Specimen in Yale University Museum, diamond number 157. Pages 144 and 153.

FIGURE 11.—*Melonites multiporus;* reconstruction, showing probable form of initial plate 1′ before resorption had taken place. This figure is adapted from area *A*, plate 2, figure 2. Magnified 2 diameters. Page 145.

FIGURE 12.—*Melonites multiporus;* interambulacrum in which the arrangement is very clear from the size of the plates. Column 4 is peculiar in originating later than in any other specimen seen; compare with photographic figure, plate 4, figure 18. Life size. Page 147.

FIGURE 13.—*Melonites multiporus;* showing dorsal portion of interambulacrum and the rhombic form of newly introduced plates. The line *X Y*, shows that 8 columns exist in the dorsal area, although being strung out they could not be counted in a horizontal plane at the same point (compare figure 1, page 164); *P*, a pentagonal plate but not a terminal of a column. Genital plates *G* have 3 or 4 pores; ocular plates *O* are imperforate. Specimen in Johns Hopkins University. Magnified 2 diameters. Pages 149, 155.

FIGURE 14.—*Melonites multiporus;* showing variation. Columns 5, 6 and 7 are normal in introduction, but column 8 originates in a hexagonal plate, 8, which attains its extra side by making a reëntrant angle into the adjacent octagonal plate *O*. Specimen in Wagner Free Institute of Philadelphia, accession number 3226. Life size. Page 151.

FIGURE 15.—The same. Reconstruction of plate 8 with a pentagonal form, when as a consequence the adjacent octagonal plate, see figure 14, becomes a heptagon, *H*. Page 151.

FIGURE 16.—*Melonites multiporus;* showing variation. The initial plate of column 3 is pentagonal instead of hexagonal (compare figure 11). The second plate, *H*, of column 3 is heptagonal. The initial plate of column 4 is also heptagonal. Specimen in Yale University Museum, diamond number 157. Magnified 2 diameters. Page 152.

FIGURE 17.—*Melonites multiporus;* showing variation. There are two accessory pentagons, *P*, *P′*, which are not terminal plates of newly added columns, lying next the terminal pentagon of column 8, with its adjacent heptagon. Specimen in Museum of Comparative Zoölogy, catalogue number 2995. Magnified 1.5 diameters. Page 153.

All the *Melonites* figured on this plate are from the Saint Louis group, Subcarboniferous, Saint Louis, Missouri.

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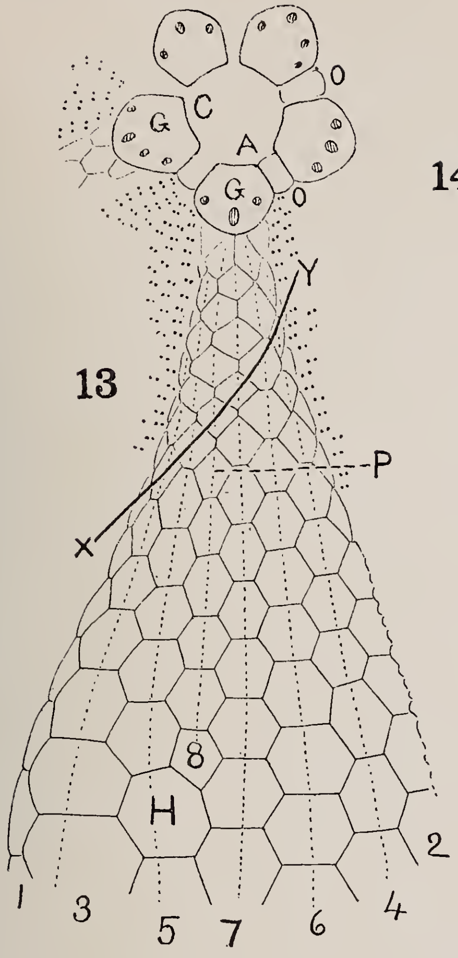

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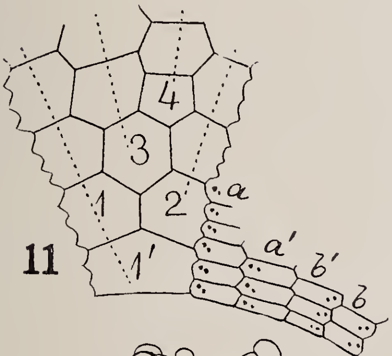

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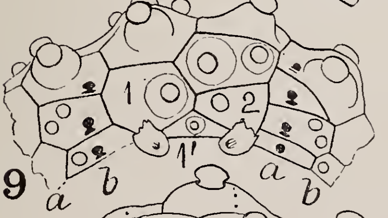

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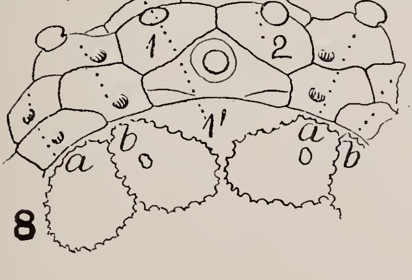

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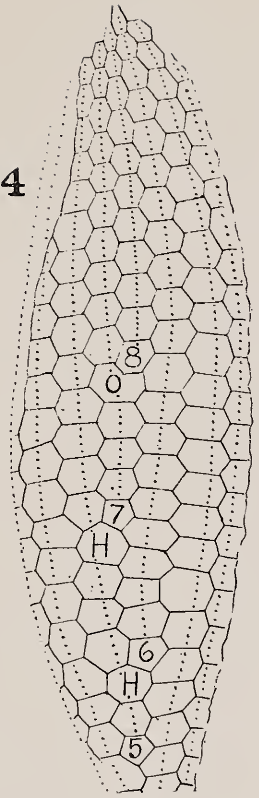

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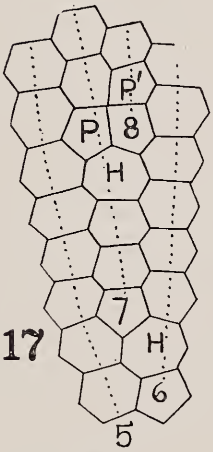

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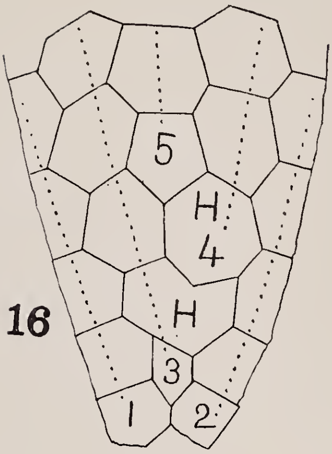

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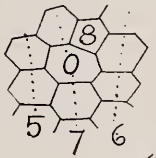

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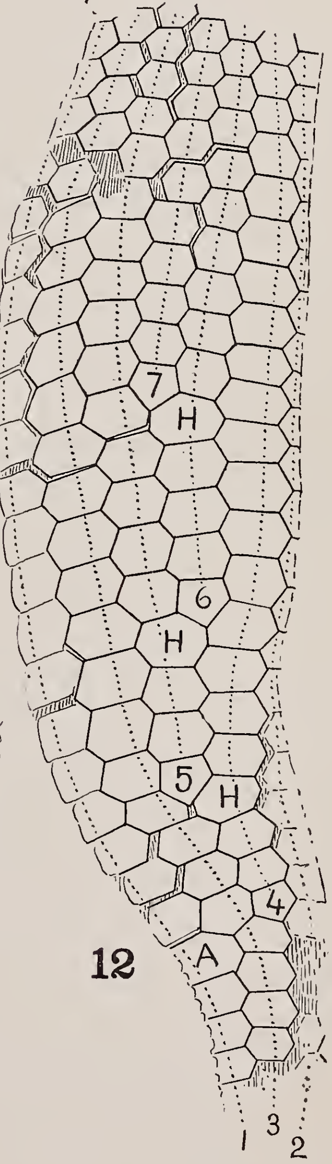


PALEOZOIC ECHINI.

18

19

EXPLANATION OF PLATE 4.

FIGURE 18.—*Melonites multiporus.* Interambulacrum *A* is the area from which the figure 12, plate 3, was drawn. The arrangement is very clear, on account of the size of the plates. This area is peculiar in that the fourth column originates much later than usual; also a hexagonal plate, *A*, exists in place of a lateral pentagonal plate and compensates for the loss of a side in plate 4; otherwise the arrangement in this interambulacrum is perfectly normal and serves as a type of the method of growth of this area. In interambulacrum *C*, which is preserved only at ventral portion, the fourth column originates in a pentagonal plate, 4, much earlier than in interambulacrum *A*. This different rate of introduction of the same numbered column in two areas is very unusual (see tabulations, pages 165–170). Spine bosses are visible in the lower part of the figure. The ambulacra *B* and *I* have 4 columns of plates ventrally, a, a', b', b, and in later growth new columns are added in each half-area, as usual (compare with plate 2, figure 4). Saint Louis group, Subcarboniferous, Saint Louis, Missouri. This specimen was in the Student Collection, Harvard University, catalogue number 316, but is now transferred to the Museum of Comparative Zoölogy, catalogue number 2990. Life size. Page 147.

FIGURE 19.—*Melonites giganteus,* Jackson. View from ventral area. (Compare with plate 5, figures 21–24, for detail.) Areas are lettered as in the table, page 180. The portion of ambulacrum *B* which is marked *X* is that area which is represented in plate 5, figure 24. In the same ambula crum at *Y*, by careful scrutiny of the figure, 6 columns of plates may be seen in the half-ambulacrum. The several interambulacral areas show the method of introduction of columns by terminal pentagonal with adjacent heptagonal plates, as described. The plates are thickly studded with spine bosses, which show as mammillate points. The specimen, which is from Lower Subcarboniferous, Bowling Green, Kentucky, is in the Museum of Comparative Zoölogy, catalogue number 2989. Nearly life size. Page 172.

EXPLANATION OF PLATE 5.

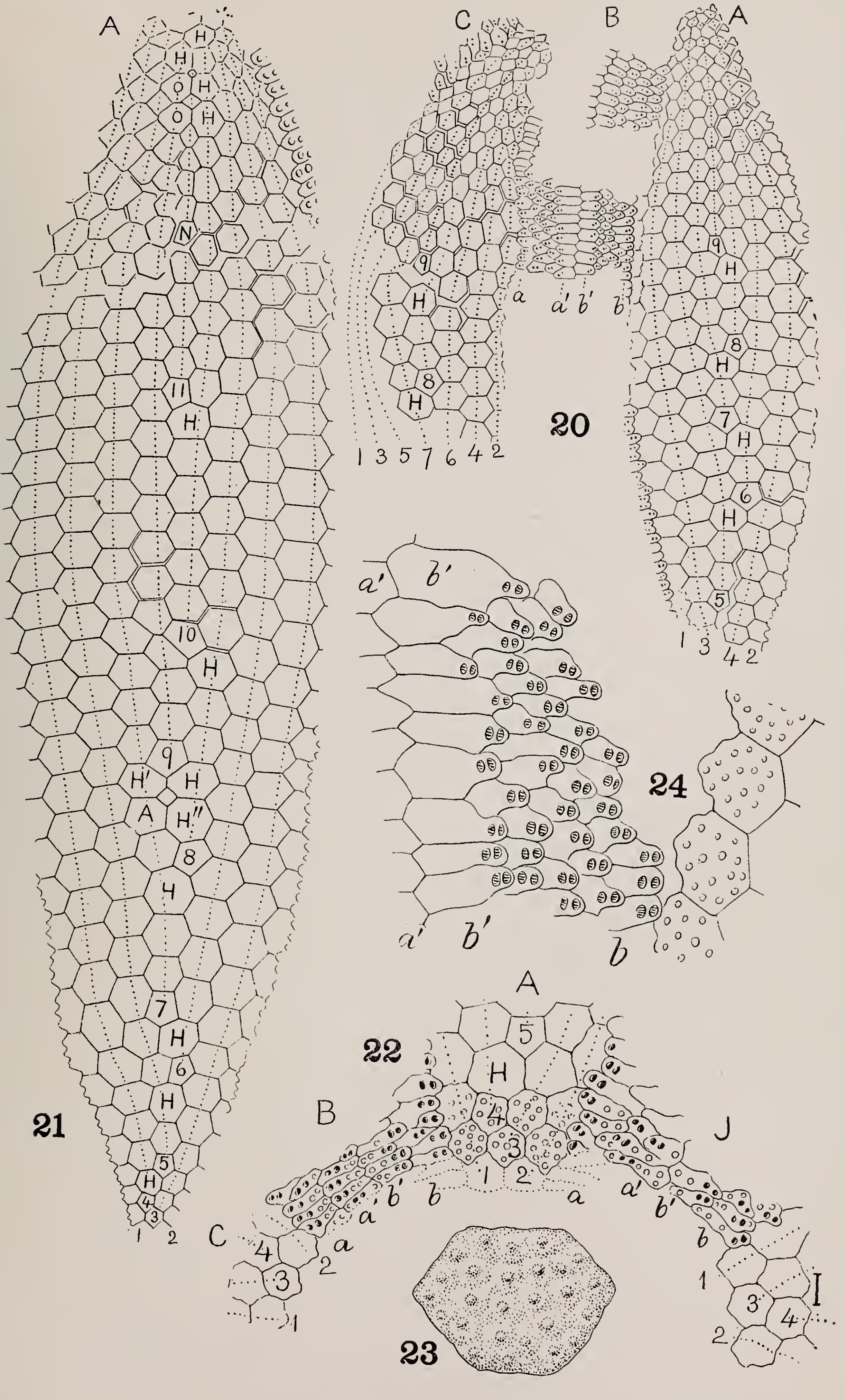
FIGURE 20.—*Melonites multiporus;* showing 9 columns of plates in 2 interambulacral areas and the rhombic form of newly introduced plates dorsally. The arrangement of the columns and plates is nearly normal throughout. The ambulacral area should be compared with plate 2, figure 4, for the relations between the structure of the ventral border and the ambitus; also with *Oligoporus*, plate 6, figures 25 and 30; also compare with figure 1, page 191, for the relations expressed in that more primitive genus. Saint Louis group, Subcarboniferous, Saint Louis, Missouri. Specimen in Museum of Comparative Zoölogy, catalogue number 3005. Life size. Pages 149, 153.

FIGURE 21.—*Melonites giganteus*, Jackson. Interambulacrum showing arrangement and method of introduction of 11 columns of plates. Column 4 originates to the left of the center (compare table, page 180), but the other 8 columns added all originate in the theoretically correct position. Below pentagon 9 is a tetragonal plate, which is really the first plate of the ninth column. Associated with this plate are a hexagon, *A*, and 2 accessory heptagonal plates, *H′* and *H″* (compare with ninth column in the four other areas, table, page 180). The eleventh column drops out before reaching the dorsal termination of the area. Associated with the two last formed tetragonal plates of the eleventh column are 4 heptagonal plates, *H*, and 2 octagonal plates, *O*, which compensate for loss of sides in the tetragonal plates. Recently added plates in the dorsal area are more or less rhombic. Compare with tabulation of the specimen, page 180, of which this figure represents area *A;* also compare with area *A* in photographic figure, plate 4, figure 19. Life size. Page 173.

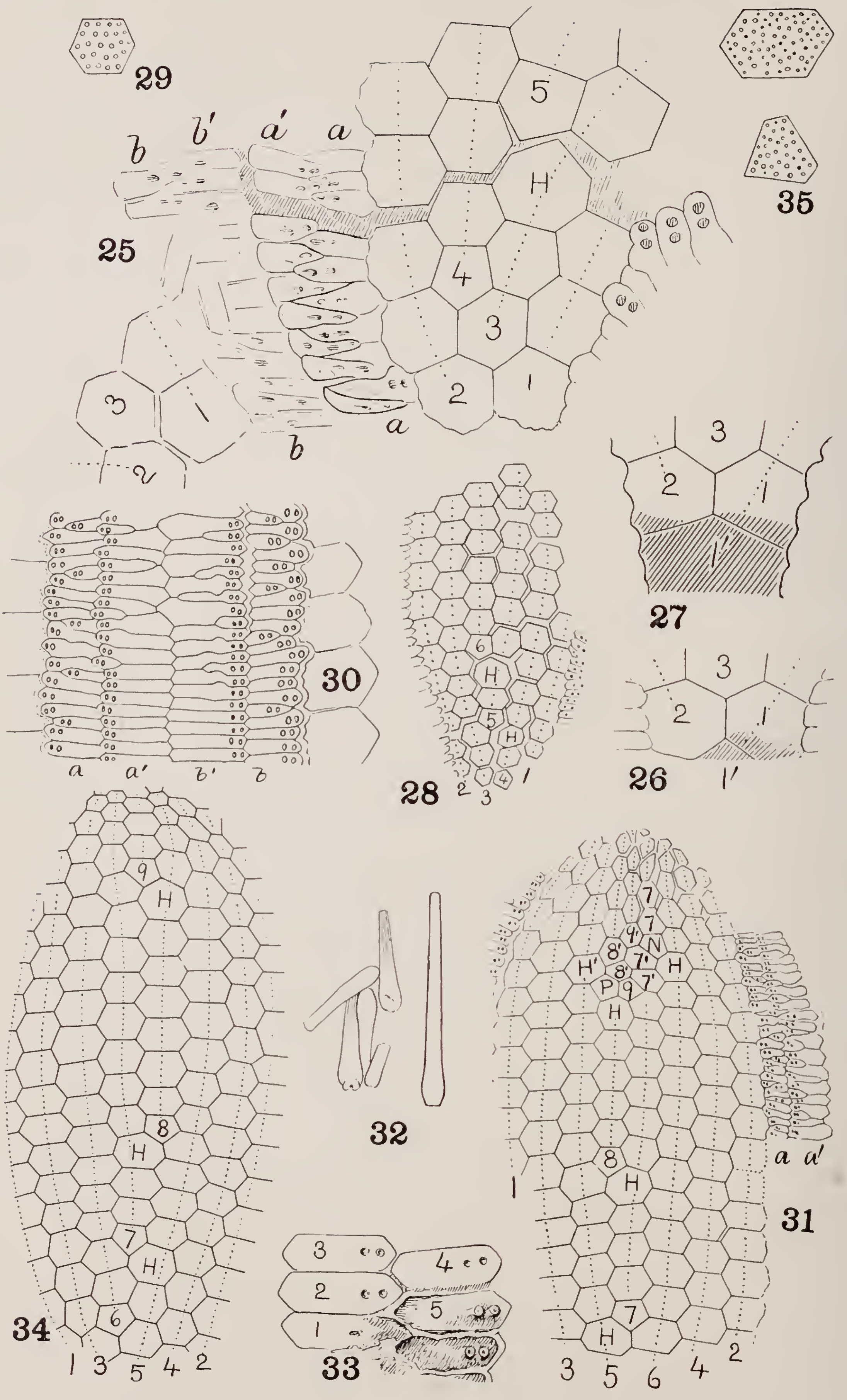
FIGURE 22.—The same specimen; showing the ventral termination of 3 interambulacra, *A*, *C* and *I*, and 2 ambulacra, *B* and *J*. The latter have 4 columns of plates ventrally, like *Melonites multiporus* (plate 2, figure 2). The dotted lines at the ventral border of area *A* indicate a restoration of the 2 plates which are wanting in all 5 interambulacra. Magnified 2 diameters. Compare with same areas in photographic figure, plate 4, figure 19. Magnified 2 diameters. Page 174.

FIGURE 23.—The same specimen; interambulacral plate with spine bosses. Compare with photographic figure, plate 4, figure 19. Magnified 4 diameters. Page 174.

FIGURE 24.—The same specimen; ambulacral detail, taken from right hand lower side of area *B* at the point *X* (see photographic figure). Only 5 columns of ambulacral plates are seen in this figure, whereas 6 occur higher up on the corona, in each half ambulacrum, as at *Y* (plate 4, figure 19). This area was figured, however, as showing detail the clearest of any portion for figuring. Magnified 2 diameters. Figures 21–24 are from the same specimen as plate 4, figure 19. Page 174.



PALEOZOIC ECHINI.



PALEOZOIC ECHINI.

EXPLANATION OF PLATE 6.

FIGURE 25.—*Oligoporus coreyi*, M. and W.; viewed from the inside, so areas must be reversed for comparison with outside. Interambulacra have 2 plates ventrally, as in *Melonites*, plate 2, figure 3. In the right hand area plate 1 is broken; plate 2 is entire and has an angle, like plate 3, figure 10, for reception of single initial plate. Columns 3, 4, 5 are introduced as in *Melonites*. The ambulacra ventrally have 2 plates, *a b;* dorsally these pass into 4 plates, *a a′* and *b′ b*. This explains the relations of the several columns of ambulacral plates in *Oligoporus*, figure 30, and *Melonites*, plate 2, figures 2, 4, to the 2 columns characteristic of most Echini, plate 8, figures 43, 47, 48. (See diagram on page 191.) Subcarboniferous, Indiana. Specimen in Museum of Comparative Zoölogy, catalogue number 3008. Magnified 3 diameters. Pages 142, 189.

FIGURE 26.—The same; restoration of ventral border of right interambulacrum of figure 25, showing dorsal border of the supposed initial plate 1′ in place; restored portions are shaded. Page 192.

FIGURE 27.—The same; further restoration, showing the probable form of plates 1 and 2 and initial plate 1′ before resorption had taken place; compare with plate 3, figures 8–11, and plate 7, figure 42. Page 192.

FIGURE 28.—The same; another interambulacrum in same slab and probably the same individual as figure 25; viewed from the inside, showing arrangement of plates. Life size. Pages 186, 193.

FIGURE 29.—The same; interambulacral plate, with spine bosses. Magnified 1.5 diameters. Page 187.

FIGURE 30.—*Oligoporus danæ*, M. and W.; ambulacral area. The columns *a*, *a′*, *b′*, *b* compare with 2 columns, *a*, *b*, seen ventrally in figure 25. Isolated plates occur in the middle of each half ambulacrum; these appear to be the equivalent of plates *c*, *d* in *Melonites*, plate 2, figure 4. Keokuk group, Subcarboniferous, Keokuk, Iowa. Specimen in Musuem of Comparative Zoölogy, catalogue number 2998. Magnified 2 diameters. Page 190.

FIGURE 31.—*Oligoporus danæ;* showing arrangement and development of interambulacrum. A break occurs in column 9, when after 2 intervening rows are built, plates are again added to column 9. Considerable irregularity of plates occurs at this area, as described. Keokuk group, Subcarboniferous, Warsaw, Illinois. Specimen in Museum of Comparative Zoölogy, catalogue number 2997. Life size. Page 193.

FIGURE 32.—*Oligoporus danæ;* spines. Keokuk group, Subcarboniferous, Alton, Illinois. Specimen in Yale University Museum. Magnified 6 diameters. Page 196.

FIGURE 33.—*Oligoporus danæ;* showing enlargement of pores and spaces between plates by silicification. Keokuk group, Subcarboniferous, Alton, Illinois. Specimen in Yale University Museum. Magnified 4 diameters. Page 197.

FIGURE 34.—*Oligoporus danæ;* showing arrangement and development of area, after Meek and Worthen (30). Modified from their figure by correcting orientation, omitting ambulacra and spine bosses, and introducing numbers and dotted lines to accentuate columns. Keokuk group, Subcarboniferous. Page 197.

FIGURE 35.—*Oligoporus nobilis*, M. and W.; plates showing spine bosses. Keokuk group, Subcarboniferous, Keokuk or Warsaw, Illinois. Specimen in American Museum of Natural History. Magnified 1.5 diameters. Page 198.

EXPLANATION OF PLATE 7.

FIGURE 36.—*Rhoechinus gracilis,* M. and W.; sandstone cast, seen from the inside, so that areas indicated by numbers and letters must be reversed for comparison with the outside. The specimen shows more or less completely the arrangement and development of plates in five interambulacral areas. The ambulacral areas are clearly seen, but the individual plates are not visible in the specimen; they are restored in area *J* as indicated by dotted lines. Genital and ocular plates are visible dorsally. Waverly group, Subcarboniferous, Menifer county, Kentucky. Specimen in Student Collection, Harvard University. Catalogue number 115. Magnified 2 diameters. Page 201.

FIGURE 37.—*Rhoechinus gracilis;* ambulacral detail. Burlington group, Subcarboniferous, Burlington, Iowa. After Meek and Worthen (31). Magnified 2 diameters. Page 202.

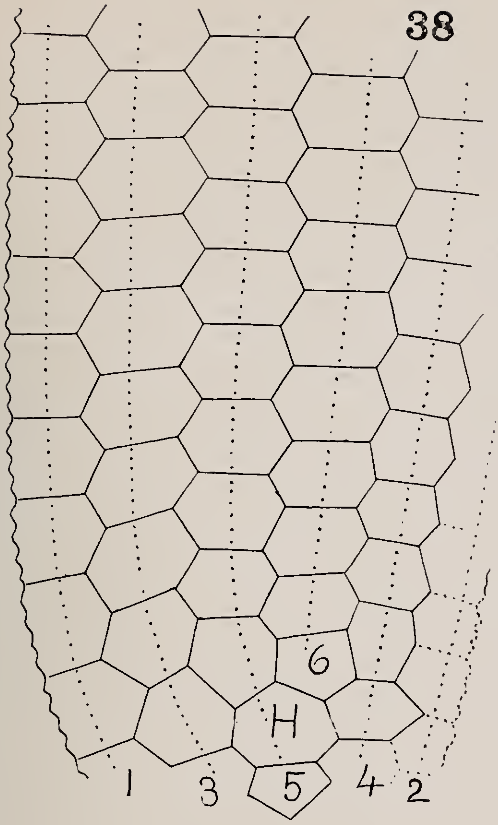
FIGURE 38.—*Palæechinus gigas,* M'Coy; interambulacrum showing plate arrangement. The right column, 2, of adambulacral plates is restored, as indicated by dotted lines. Carboniferous, Clitheroe, Lancashire, England. Slightly enlarged. Page 204.

FIGURE 39.—*Palæechinus gigas;* detail of one half-ambulacrum. Carboniferous, Clitheroe, Lancashire, England. Figures 37 and 38 from specimen in the Museum of Practical Geology, Jermyn street, London; compare with figure 1, page 191. Magnified 1.5 diameters. Page 205.

FIGURE 40.—*Rhoechinus elegans,* M'Coy; details of ambulacrum. This should be compared with the ambulacrum at ventral border of area in *Oligoporus,* plate 6, figure 25; also figure 1, page 191. Carboniferous, Hook Head, Ireland. Specimen in Museum of Comparative Zoölogy, catalogue number 3002. Magnified 4 diameters. Page 205.

FIGURE 41.—*Lepidocidaris squamosus,* M. and W.; showing arrangement of plates and introduction of the sixth, seventh and eighth columns. Compare with *Melonites,* plate 5, figure 20, and *Archæocidaris,* plate 8, figures 44, 45. The ambulacra consist of 2 columns ventrally, but higher up pass into 4 imperfect columns. Compare with *Oligoporus coreyi,* plate 6, figure 25. Burlington group, Subcarboniferous, Burlington, Iowa. Specimen in Museum of Comparative Zoölogy, catalogue number 3026. This specimen is the type of the genus and species. Life size. Page 220.

FIGURE 42.—*Lepidechinus rarispinus,* Hall; showing a single initial plate, 1′, ventrally, succeeded by 2 plates, 1, 2; (compare with plate 3, figures 8–11, plate 6, figures 24–26, plate 9, figure 54; also figures 3 and 4, page 234.) More columns, from 3 to 9, inclusive, are added dorsally, as indicated by numbers and dotted lines. The plates on account of their imbrication are not so regular and are different in form from *Melonites* and *Oligoporus;* they also differ from these in the rapid or accelerated rate of introduction of columns. Waverly group, Warren, Pennsylvania. Specimen in the collection of Professor C. E. Beecher, of New Haven, Connecticut. Magnified 2 diameters. Page 226.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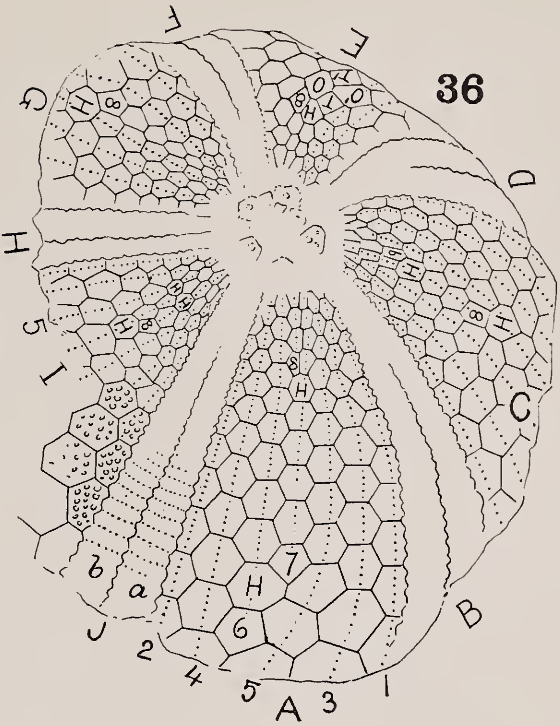
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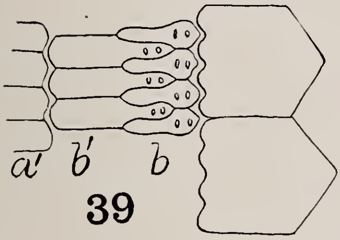
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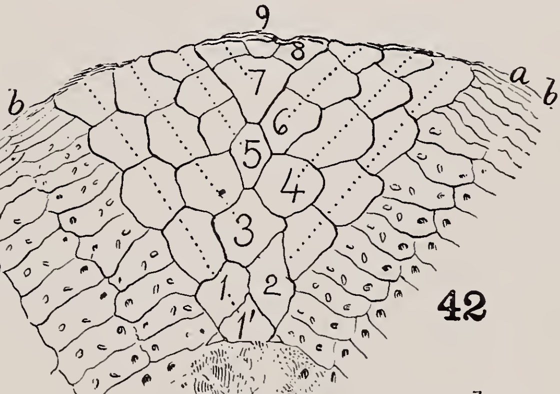
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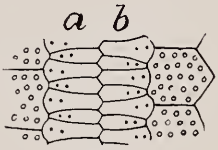
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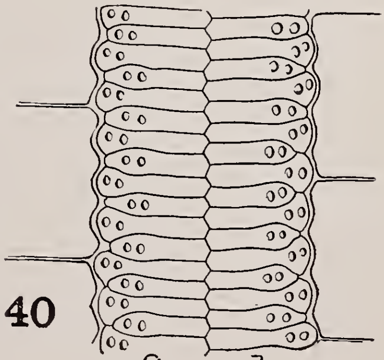
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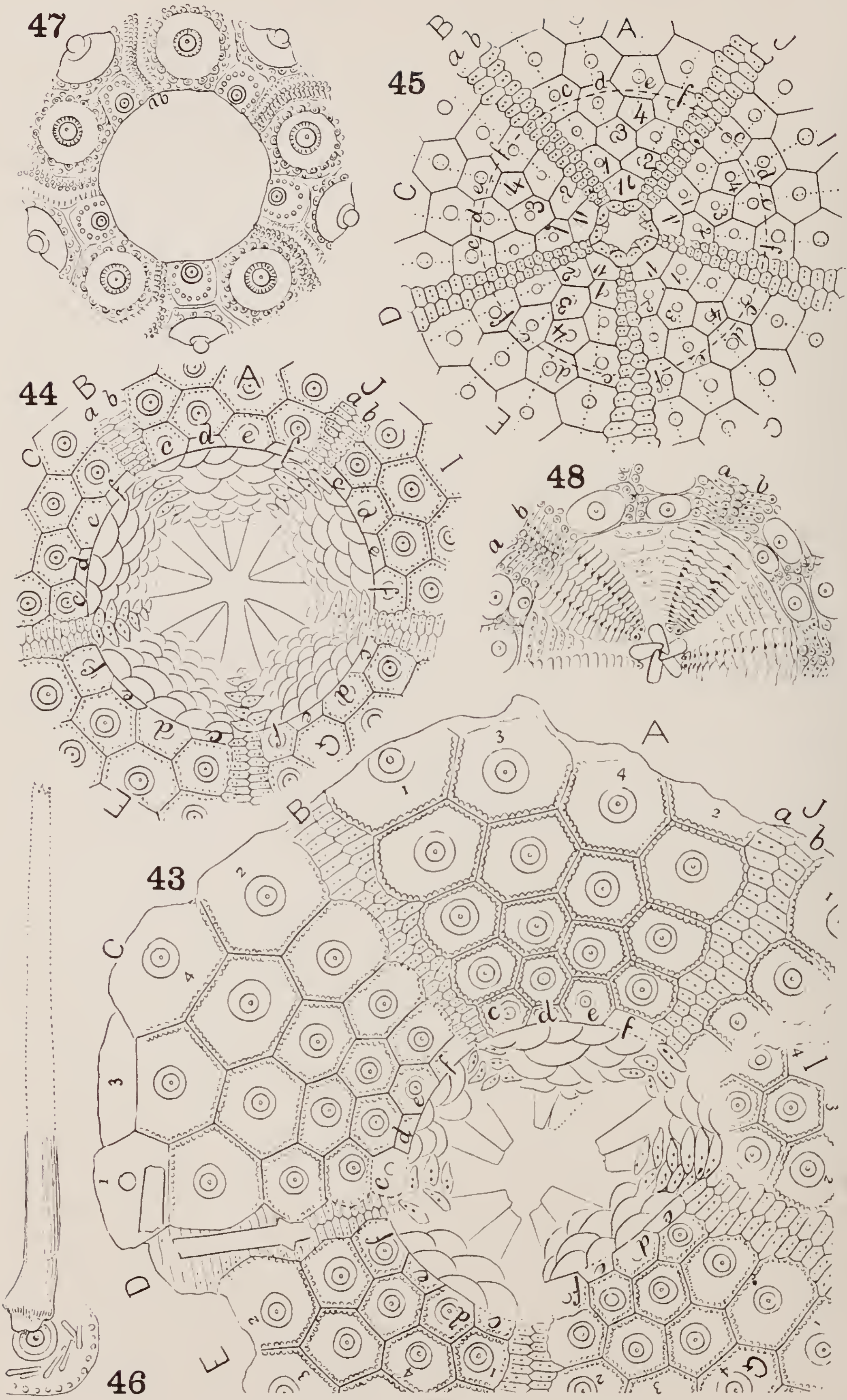
PALEOZOIC ECHINI.



PALEOZOIC ECHINI.

EXPLANATION OF PLATE 8.

FIGURE 43.—*Archæocidaris wortheni*, Hall; showing 4 columns of plates in each interambulacrum. Ventrally the plates of the corona have been resorbed by encroachment of the peristome. In areas *A* and *C*, plates *c* and *e* are nearly full sized, but somewhat resorbed ventrally; plates *d* and *f* are less than the upper half of a hexagon, the rest of the plate having been resorbed. In areas *E* and *G* a reversed condition occurs, plates *c* and *e* being less than the upper half of a hexagon, while plates *d* and *f* are large, with only their ventral border resorbed. Ambulacra in the corona consist of 2 columns, *a*, *b*, of low, regular plates. Plates not present in the specimen are indicated by dotted lines. On the peristome dental pyramids lie opposite the interambulacra. In area *A* one side of a pyramid is restored. Interambulacral plates of the peristome are scale-like, imbricating adorally. Ambulacral plates on the peristome are somewhat irregular, drawn out laterally, and each has 2 pores in a horizontal plane. The columns of interambulacral plates of the corona are numbered 1, 2, 3, 4. For explanation of the method of arriving at these numbers compare with figure 45. Saint Louis group, Subcarboniferous, Saint Louis, Missouri. Specimen in the American Museum of Natural History. Magnified 2 diameters. Page 214.

FIGURE 44.—The same; restoration of figure 43. Interambulacrum *I* is restored and the plates are more regular and carried further up on the peristome than shown in the specimen. Page 218.

FIGURE 45.—The same, showing ventral border of corona, as in figure 44, and a reconstruction of plates, which have been resorbed. 10 ambulacral plates surround the mouth, and pyramids are indicated on the border of the peristome. Interambulacra are restored with the same arrangement as traced in *Melonites* and other genera; column 4 is right-handed in areas *A* and *C* and left-handed in *E*, *G*, *I*. Introducing plates by this method, the row of plates *c*, *d*, *e*, *f* above the dotted (resorption) line corresponds with the ventral row of plates in figure 44. In the reconstruction a reasonable proportionate size of plates is maintained, and they meet almost in the center. Compare with plate 3, figures 8–11; plate 7, figures 41, 42; plate 9, figures 54, 55; figure 1, page 164, and figures 3, 4, page 234. Page 219.

FIGURE 46.—*Archæocidaris wortheni;* plate with primary and secondary spines· Saint Louis group, Subcarboniferous, Saint Louis, Missouri. Catalogue number 3028. Magnified 2 diameters. Page 217.

FIGURE 47.—*Cidaris florigemma*, Phil.; showing alternation of large and small plates at ventral border of interambulacra, as in *Archæocidaris*. By readjustment the ventral plates, like those dorsally, have complete sets of spine bosses. Coral Rag, Wiltshire, England. Catalogue number 2005. Life size. Page 215.

FIGURE 48.—*Cidaris tribuloides*, L.; showing alternation of ventral interambulacral plates of corona, as in figures 44, 47. Ambulacra extend on to the peristome as two columns of plates, as in *Archæocidaris*, but differ in that the pores are vertically superimposed. Interambulacral plates on the peristome imbricate adorally, as in *Archæocidaris*. Recent, Panama. Catalogue number 404. Magnified 2 diameters. Page 218.

Specimens of figures 46, 47, 48 are in the Museum of Comparative Zoölogy.

Explanation of Plate 9.

Figure 49.—*Melonites septenarius*, Whitfield. In the ambulacrum only a portion of the left half is complete, showing columns *a*, *a′*, with two intermediate columns, and one column, *b′*, of the right half. Column 7 in the interambulacrum has 5 columns on the left and 1 on the right. This is the most extreme irregularity in the position of a column of any echinoid seen. Pentagonal plate *P* and heptagonal plate *A*, are local and most unusual irregularities. Warsaw group, Subcarboniferous, Buzzard Roost, Franklin county, Alabama. Specimen in American Museum, New York. Life size. Page 182.

Figure 50.—*Oligoporus missouriensis*, Jackson. Ambulacra have fan-shaped plates opposite the sutures of interambulacral plates. Interambulacra have 5, as in area *C*, or 6 columns of plates; when the latter, only for a brief period, as in area *A*. Adambulacral plates are rounded on their outer borders (compare with plate 6, figure 30). Irregular pentagons and heptagons (see text). Subcarboniferous, Webb City, Missouri. Specimen in Museum of Comparative Zoölogy, catalogue number 3078. Life size. Pages 150, 184.

Figure 51.—The same. Ambulacral detail of one half-area. Magnified 2 diameters. Page 184.

Figure 52.—The same, showing genital and ocular plates. Magnified 2 diameters. Pages 156, 186.

Figure 53.—*Lepidesthes wortheni*, Jackson. Ambulacrum *B* ventrally has 4 columns of hexagonal plates (compare with *Melonites*, plate 2, figure 2); at the ambitus there are 8 columns of subhexagonal plates. Pores are in the center of the plates. Interambulacra *A* and *C* ventrally have 4 columns of plates; one of these columns drops out (see area *C*, plate *A*) in passing dorsally, and three columns continue to the dorsal pole. Two dental pyramids, *D*, *D*, are visible ventrally. These are seen plainly on the other side of specimen. Incrusting bryozoa obscure some details. Keokuk group, Subcarboniferous. Specimen in the Boston Society of Natural History, catalogue number 11601. Magnified 2 diameters. Page 207.

Figure 54.—*Pholidocidaris meeki*, Jackson. Ambulacral plates have central pores surrounded by a depressed areola. Interambulacrum has ventrally a single plate, 1′, and passing dorsally new columns are added up to 6. In column 2 plates are apparently wanting, as indicated by the dotted line, and an ambulacral plate, *A*, has been shoved out of place. A few spines are scattered over the test; dental pyramids, *D*, exist ventrally. Below plate 1′ is a plate which is apparently an interambulacral plate of the peristome. Keokuk group, Subcarboniferous, Warsaw, Illinois. Specimen in Museum of Comparative Zoölogy, catalogue number 3070. Life size. Page 210.

Figure 55.—Immature *Cidaris papillata*, Leske; showing resorption of corona by encroachment of the peristome. Spine tubercles are being cut away together with the plates. Showing also imbricating interambulacral plates of the peristome. Recent (compare with plate 8, figure 48). After Lovén (Echinologica, page 22). Magnified. Page 215.

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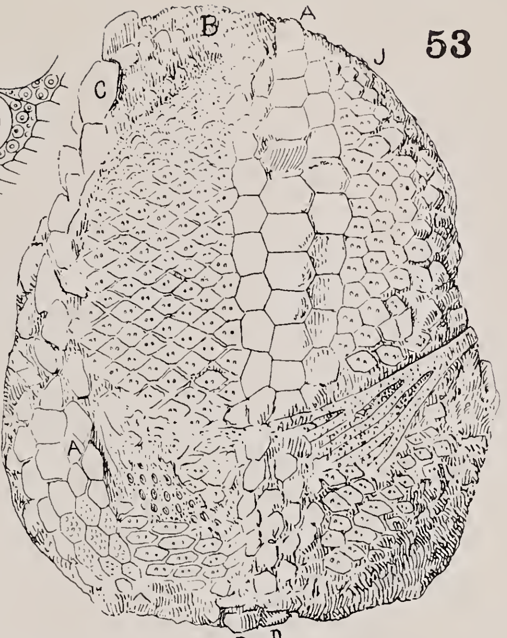

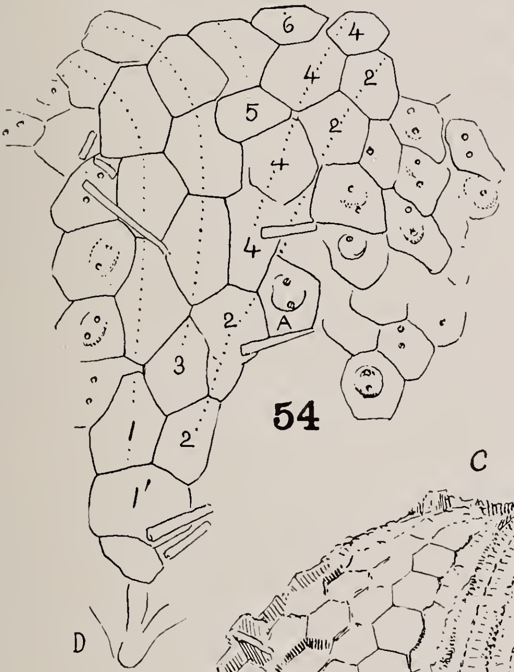

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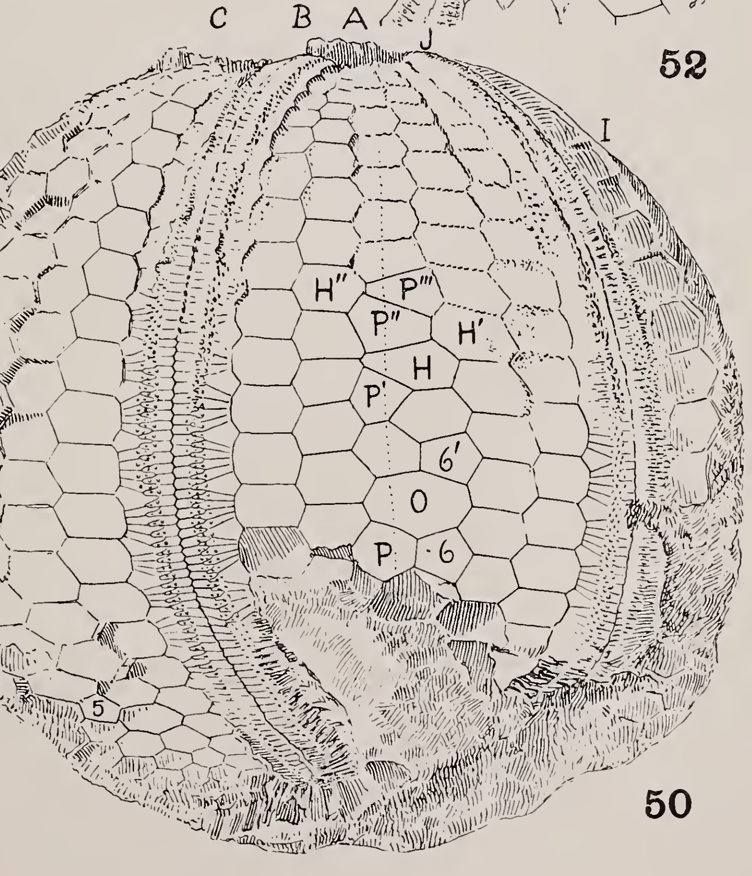

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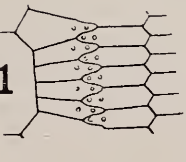

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PALEOZOIC ECHINI.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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DECOMPOSITION OF ROCKS IN BRAZIL

BY JOHN C. BRANNER

(*Read before the Society August 28, 1895*)

CONTENTS

INTRODUCTION.

In writing of Brazil, Louis Agassiz* says that—

> "The decomposition of the surface rocks to the extent to which it takes place is very remarkable, and points to a new geological agency thus far not discussed in our geological theories. It is obvious here . . . that the warm rains falling upon the heated soil must have a very powerful action in accelerating the decomposition of rocks. It is like torrents of hot water falling for ages in succession upon hot stones. Think of the effect, and instead of wondering at the large amount of decomposed rocks which you meet everywhere you will be surprised that there are any rocks left in their primitive condition."*

By decomposition, decay and disintegration as used in the present paper I refer only to the phase or phases of rock decay which can be detected by the eye. I shall not attempt any detailed analysis of the chemical processes of decomposition or of the mineral changes. These changes I assume to be the same in the main as those accompanying rock decomposition in other parts of the world, with differences only in the rate at which it goes on and in the degree of oxidation known to exist between warm and cold climates.† No distinction is made between disintegration and decomposition, for the former is believed to be incipient decay, however slight the chemical changes may be.

EVIDENCES AND RESULTS OF DECOMPOSITION.

DECAY IN PLACE.

General distribution and character of the decomposition.—Disintegration of rocks in Brazil is both profound and widespread. The working out of structural geology over limited areas is often made altogether impossible by the breaking down of the stratification and by the mingling of the products of decomposition in land-slides and by the creep of the soil, while the decay of the crystalline rocks often renders the determination of their constituent minerals difficult or altogether impossible.

This deep decomposition is not confined to any particular part of the country, but it is a pretty constant feature of the geology from the equator

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* Journal in Brazil, 89. Am. Jour. Sci., 2d ser., vol. xl, 1865, p. 390.

† See Subaërial decay of rocks and the origin of the red color of certain formations. Bull. 52 U. S. Geol. Survey. I. C. Russell. This bulletin contains a partial bibliography of the subject of rock decay.

to the southernmost part of Rio Grande do Sul. Neither is decay confined to the immediate surface, but it penetrates the solid rocks as far as they are affected by varying temperatures or by crevices, however obscure, along which water can enter. The rocks necessarily vary more or less in their resisting powers, but they are all more or less affected.

Rocks are attacked in three ways:

First, by surface disintegration;
Second, by exfoliation;
Third, by profound decay in place.

Areas studied and their characteristics.—The most striking instances of rock decay which have fallen under my own observations have been in the vicinity of Rio de Janeiro and in the states of Minas Geraes, Pernambuco and Pará.

About Rio de Janeiro this decay is to be seen on every hand, and has been recorded by almost every geologist who has visited that region. The road from the city to Tijuca has many cuts in the soft decayed gneiss; the road which ascends toward the Tijuca peak and that leading from near Tijuca toward Pedra Bonita and the Chinese view reveal the decayed rock in almost every cut. West of the Botanical gardens the road leading toward the Gavêa expose in several places cuts 20 and 30 feet deep in the decomposed rock.

In the Larangeiras suburb many deep cuts have been made in this material, especially close to the foot of the hill on either side of the valley toward its upper end. At one place in the upper part of the Larangeiras a tunnel more than 100 feet long driven into the foot of the mountain for the purpose of making a cooling chamber for domestic purposes penetrates only softened gneiss. A tunnel cut through the hill in 1887 to connect Larangeiras and Rio Comprido passed through more than 100 feet of decayed rock on the Rio Comprido side.

In 1879–'80 a large reservoir was built on the Morro do Pedregulho near the Ponta do Cajú in the northwestern outskirts of the city of Rio. The hill was originally 225 feet high, and the site for the reservoir was prepared by cutting off the top of the hill to a depth of 65 feet.* This thickness of the rock was decayed gneiss, and undecomposed rock was not found at this depth of excavation.

In one of the plates accompanying Pissis' paper he represents the decomposed gneiss at the base of the Corcovado at Rio as having a depth of 120 meters.† I know that the gneiss at this point is profoundly decomposed, but I never saw it exposed to such a depth as he there repre-

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* Relatorio sobre o reservatorio D. Pedro II. W. Milnor Roberts. Revista de Engenharia, ii, no. 7, Rio de Janeiro, July 15, 1880, pp. 106, 111, 112.

† La position géologique des terrains de la partie australe du Brésil. M. A. Pissis, 1842, p. 358.

sents. I suspect that his measurement was a vertical one and not made at right angles to the rock face.

Professor Hartt makes many references to the deep decomposition of the rocks, though he seldom gives any figures on the subject. Inasmuch as he was of the opinion, when he wrote his book upon Brazilian geology, that that country had been glaciated, the materials called drift by him may usually be put down as decomposed rock in place or but little disturbed.*

George Gardner, the English botanist, mentions 30 to 40 feet of clay about Rio de Janeiro.†

Mr Darwin ‡ says that—

> "near Rio every mineral except the quartz has been completely softened, in some places to a depth little less than 100 feet. . . . At Rio it appeared to me that the gneiss had been softened before the excavation (no doubt by the sea) of the existing broad, flat-bottomed valleys. . . . At Bahia the gneiss rocks are similarly decomposed."

On the Nictheroy side of the bay there are several exposures of decayed and half-decayed rocks on the high headland near the northern end of the Jurujúba bay. Here the waves have undermined the materials, but while they are still hard enough to stand in vertical cliffs, they are far from being as hard as the ordinary undecomposed gneiss. These cliffs are in places as much as 100 feet in height.

Along the railway leading from Nictheroy to Nova Friburgo gneiss is the rock of the country, and it is deeply decomposed along the whole route, showing here and there the dome-like peaks so characteristic of this coastal region. At Cantagallo this decomposition is quite as marked as it is at Rio de Janeiro. One of the exposures shows a hillside where disintegration has penetrated more than 100 feet, and as the rocks at the bottom are quite as soft as those at the top it seems safe to presume that decomposition has extended still deeper.

The rocks through the region from Cantagallo to Campos are all gneisses and granites, and show everywhere the same deep decomposition as that about Rio de Janeiro.

Petropolis, in the Organ mountains, is in a region of gneiss, and as the valleys about it are narrow the sight of the deep cuts in the decomposed rocks is a common one there. Others are exposed along the railway leading up from the foot of the Serra.

Good cuts in decomposed gneiss are exposed along the line of the Cen-

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* Geology and Physical Geography of Brazil. Ch. Fred. Hartt. Boston, 1870, pp. 25, 28, 31, 340, 508, 509, 564. On Hartt's change of views on the subject of glaciation see "The Supposed Glaciation of Brazil." J. C. Branner. Journal of Geology, vol. i, 1893, pp. 753–772.

† Travels in the Interior of Brazil. George Gardner. London, 1846, p. 11.

‡ Geological Observations. Charles Darwin. 2d ed., London, 1876, pp. 427, 428.

tral railway (formerly called D. Pedro Segundo) leading from Rio de Janeiro across the Serra do Mar. Some of these cuts are still exposed to view, but owing to the tendency of the soft material to wash and slide the railway company has been obliged to cover many of them with a sort of stone pavement. Some of the most interesting cases with which I am acquainted are those of the tunnels on the railway line where it crosses the Serra to Barra do Pirahy'. All of these tunnels are in granites and gneisses, and aggregate 5,189 meters in length. The rocks are so decomposed that over 2,000 meters of this distance required to be lined with masonry,* and one of the tunnels is said to have required recutting on account of the sliding of the decomposed rocks.

Along the railway between Entre Rios and the top of the Mantiqueira are many noteworthy cuts in decomposed gneiss. At one point the road was so often and so seriously embarrassed by the slipping of the decomposed materials that the engineers were finally obliged to construct a tunnel—the Cachoeira tunnel. At the crest of the Serra, where the railway passes through the "Gargante de João Ayres," the decayed rock of the deep cut had to be kept off the track by enormous walls 22 feet high, though the banks were sloped back as usual to a height of 78 feet.†

On the União e Industria road, a highway that crosses the mountain and extends from Petropolis to Juiz de Fora in the state of Minas, other and scarcely less striking cuts expose the decomposed rocks in many places. Some of these cuts are as much as 50 feet deep.

The São Paulo railway, from Caxoeira to São Paulo, shows similar cuts in decomposed rocks, though not so many of them. The profound decomposition of the rocks along this line has beeen the cause of not a few landslides and of at least one serious railway accident.‡ Where the railway ascends and passes over the mountain, from Santos toward São Paulo, there are several deep cuts in the decomposed rock.

In his article upon nephelene rocks in Brazil (São Paulo and Minas) Professor Derby does not state the depths to which he found the rocks decomposed in the region he describes, but one gets the impression that these depths are very considerable, for the railway cuts and tunnels are mostly in the decayed materials.§ Derby states elsewhere || that decomposition has been so general in northern São Paulo and southwestern

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* Manoel da Cunha Galvão in Revista de Engenharia, Dec. 10, 1879, pp. 6, 7. Agassiz: Journey in Brazil, p. 528. Estudo descriptivo das Estradas de ferro do Brazil. Cyro D. R. Pessôa, junior. Rio de Janeiro, 1886, p. 210.

† Estudo descriptivo das Estradas de Ferro do Brazil. Pessôa, p. 213. Revista do Inst. Hist. do Brazil, li, pt. ii, p. 202.

‡ Revista de Engenharia, ii, no. 2, Feb. 15, 1880.

§ On nephelene rocks in Brazil. O. A. Derby. Quar. Jour. Geol. Soc., vol. xliii, 1887, pp. 462–470.

|| Contribuições para o estudo da geographia physica do valle do Rio Grande. O. A. Derby. Boletim da Sociedade de Geographia do Rio de Janeiro, i, no. 4, p. 15.

Minas that there are but few rocks uncovered by soil. The famous *terra roxa* of São Paulo is derived by decomposition from the igneous rocks that cover a large part of that state.

A. Pissis says that in the Serra de Goitacazes the gneiss is changed to a reddish clay to a depth often of more than 100 meters.[*]

In the highlands of Brazil decomposition is so widespread that it is often impossible to find enough exposure of hard rock in place to work out the structure. Through the granite and gneiss regions this decomposition may be seen in the railway cuts from Rio de Janeiro across the Serra do Mar and the Serra da Mantiqueira, and this same decomposition is common wherever the granites and gneisses occur through the interior, though it is not to be inferred that there are no exposures of hard rock.

The other rocks of the highlands are mostly metamorphosed, namely, schists, itacolumites, itabirites, *jacutingas* and a recent surface formation of iron cement known as *canga*. Occasionally these rocks, especially the itacolumites, stand out as bare and rugged mountains,[†] but over a large part of region the geology is masked by a thick coating of soil, and decomposition has profoundly affected the rocks in place. Gerber notes that the gneiss is specially subject to decomposition.[‡]

James E. Mills, who lived and traveled in Brazil more than a year, in speaking of the province of Minas Geraes says:

> "The gneiss and slates are softened to great depths from the surface. I have seen sections showing a thickness of over 100 feet (estimated with the eye) of this softened rock, and yet not reaching to the bottom of it." [§]

To the traveler in Minas Geraes one of the striking sights is the enormous gullies through which the roads and mule trails often pass. These gullies are always on hillsides, though not necessarily high or steep ones, and have frequently been made by the washing out of the soft mud from the bottoms of the paths. Once the natural surface is broken by a path, the heavy rains rapidly deepen the channel, and the *tropeiros* continue to follow the old road, which sinks year after year into the earth. These gullies are always V-shaped and are often so narrow in the bottom that two loaded mules cannot pass each other in the path.

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[*] La position géologique des terrains de la partie australe du Brésil. M. A. Pissis. Mémoire de l'Inst. de France, x, 1842, p. 358. Hartt erroneously makes the depth of the decomposition given by Pissis 300 meters instead of 100. Geology and Phys. Geog. of Brazil. Ch. Fred. Hartt, p. 25.

[†] Hussak in his Relatorio Parcial, 114, notes the greater resistance of itacolumite than of schists, while Heusser and Claraz express the opinion that "metamorphic schists and itacolumite are very liable to decomposition. The decomposition of itacolumite, which is essentially quartzose, is especially characterized by a fissuring of the rock, which falls to powder." Gisement et exploitation du diamant dans la Province Minas Geraes au Brésil. Ch. Heusser et G. Claraz. Ann. des Mines, 5me sér., xvii, p. 291.

[‡] Noções da provincia de Minas Geraes. Henrique Gerber, 2d ed. Hanover, 1874, 18. Derby speaks of the difficulty of working out structure in the interior where decomposition is so deep. Archivos do Museu Nacional, iv, 1881, p. 125.

[§] Quaternary deposits, etcetera. James E. Mills. American Geologist, vol. iii, June, 1889, p. 351.

I have seen such gullies in Minas as much as 75 feet deep and possibly more than that in some instances. The banks show that the rocks have simply decomposed in place, and the decomposition is often so complete that the entire surface exposed is practically one mass of parti-colored clays.

Not the least striking thing about many of these gullies is their bright colors and the fantastic forms produced by rapid erosion.* The rocks seem to have been schists for the most part, some of them micaceous and others talcose. Quartz veins are common in them, but the quartz has broken into small angular fragments. But while gullies are washed out with amazing rapidity, the deepest ones I have seen are not on the trails first made by the early travelers more than 100 years ago. The oldest gullies seem to have reached a depth beyond which excavation has been retarded for some reason, and thereafter they widened at the top until the uppermost part of the decayed rock had been removed over an area four or five times the width of the original gully when its principal depth was reached. Some of the most remarkable of these gullies are in the region between the Serra de Mantiqueira and Ouro Branco.

Natural washouts on the sides of the hills in the campo region, between Sitio and the Ouro Preto mountains, are common in other places than the trails, however. Dent mentions these *barrancas*, as they are called, " often 100 to 200 feet deep," † between Brumado and Suassuhy.

Mr Wells thinks these barrancas are land-slides. ‡ Some of them doubtless are, but certainly not all of them.

Liais states that in about 40 years between 300,000 and 400,000 cubic meters of earth were removed from one of these barrancas. Some of the barrancas he thinks are land-slides. §

Castelnau thinks the land-slides may have been caused partly by earthquakes. ||

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* Burton's Highlands of Brazil, i, p. 74. Sud-Amérique. Charles d'Ursel. Paris, 1879, p. 55.

† A year in Brazil. H. C. Dent. London, 1886, p. 37.

‡ Three Thousand Miles through Brazil. J. W. Wells. London, 1886, vol. ii, p. 372.

§ Climats, etcetera, p. 4.

|| Expedition dans l'Amérique du Sud., i, p. 202. The barrancas about Barbacena have attracted more attention than those of any other part of the country, because Barbacena is on the highway leading from Rio de Janeiro to the gold and diamond region of Minas.

For other cases of deep decomposition see :

Penedos de Dioritos do Valle do Parahyba do Sul. Comte de la Hure. Revista do Instituto Historico do Brazil, xxix, 1866, pp. 422–429.

Hartt's Geology and Physical Geography of Brazil, pp. 145, 159.

Reise in Brasilien, Spix u. Martius. Münschen, 1823, i, p. 302.

Travels in South America. Alexander Caldcleugh. London, 1825, vol. ii, pp. 192, 210, 213, 215, 227, 229, 230, 258, 260, 282.

Beiträge zur Gebirgskunde Brasiliens. Joh. Em. Pohl. Wien, 1832, pp. 26–28. American Naturalist, Sept., 1884, vol. xviii, p. 927.

Ueber das Geognostische Verkommen der Diamanten. V. von Helmreichen. Wien, 1846, pp. 5, 7, 12, 15.

Some of the most interesting and most impressive cases of rock decay that have fallen under my observation or that I have been able to learn about are to be found in the gold mines of Minas Geraes.

The old rock mines of the Portuguese and Brazilian miners were almost without exception in decomposed rocks. These early miners, however, probably never worked mines deeper than about 100 feet.

At São João da Chapada, about 16 miles west of Diamantina, Minas Geraes, the diamond mines are in beds of schists[*] so decomposed that they stand only at the angle of repose for clays or other soft materials. This material has been penetrated to a depth of from 65 to 90 feet without hard rock being reached.[†]

In sinking a new shaft at the Morro Velho mine, in Minas, in 1868–'69, "the ground proved jointy and unfavorable for sinking for the first 12 or 13 fathoms, after which it became harder and more compact," though not yet firm.[‡] The first four months' work was in unfavorable ground (that is, decomposed rock), and as the average given was 20 feet a month, at 80 feet the rock was not yet hard. The plan and sections of the mines exhibiting the workings for January 31, 1876, show that one of the shafts was timbered to a depth of 126 feet, which is the depth of decayed rock at this point.

The present superintendent of the Morro Velho mine, Mr George Chalmers, has kindly written me as follows upon this subject: "In sinking the shafts we found it (the clay-slate) quite soft to a depth of 25 fathoms 5 feet (155 feet). It then turned to blasting rock." He thinks the decomposition does not exceed 30 fathoms on the Morro Velho property. The same gentleman writes me that at the Raposas mine the ore body and some of the country rock are decomposed in certain places to a depth of 200 feet.[§]

At the Faria mine, near Congonhas de Sabará, a depth of 164 feet has been penetrated. The rocks are soft schists, "sometimes running into genuine clays."[||]

Prior to 1825 the old Catta Preta mines, near Inficionado and about

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[*] Sur les gisements diamantiféres de Minas Geraes (Brésil). Gorceix. Comptes Rendus, xciii, 1881, p. 982. Observações sobre algumas rochas diamantiferas de Minas Geraes. Pelo Dr O. A. Derby. Archivos do Mus. Nat., iv, 1879. Rio de Janeiro, 1881, p. 127. Explorations of the Highlands of Brazil. R. F. Burton. London, 1869, vol. ii, pp. 129–132.

[†] In his monograph on the diamond M. E. Boutan (p. 134) says that this mine is 40 meters deep. He gives a plate (ii), however, made from a photograph which shows that this is a mistake—that the depth is as stated by Derby.

[‡] Thirty-ninth An. Rep. Saint John del Rey Mining Company, 1869, pp. 5, 6; Fortieth Report, pp. 5–7.

[§] Private letter, dated Morro Velho, August 3, 1895.

[||] L'or à Minas Geraes. M. Paul Ferrand. Ouro Preto, 1894, i, p. 159. Notice sur la Mine d'or de Faria. Situation au 1er Jan., 1894.

20 miles north of Ouro Preto, were worked in soft rock to a depth of more than 180 feet.*

The old English gold mines at Cocaes were at least 300 feet deep, and in the soft, friable, grayish colored micaceous iron-schist.†

The case of deepest decomposition I have been able to find recorded in Minas Geraes is that shown in the workings of the old Gongo Soco mine. The reports of the company show at a depth of 330 feet that the material was still soft; ‡ at 372 feet it was remarked § that "very little alteration has taken place in the level, and we have no alteration to remark."

Dr Gardner, who was at Gongo Soco in 1840, says the greatest depth of the mine at that time was 378 feet, and that the schists were all so soft as to require strong pillars, || while Castelnau, who visited this mine in 1843, remarks that it was worked with the pick. ¶

The Gongo Soco mine was sunk to a depth of 420 feet in 1844, but I have been unable to find out whether the rocks continued soft at this depth. **

James E. Mills, who studied the geology of Rio Grande do Sul about Lagôa da Maçã, writes me that at that place "the hard feldspathic porphyry is softened . . . to a depth of 12 or 15 feet, but the softening is by no means as extensive in this part of Rio Grande do Sul as in Minas." Professor Derby reports borings made in Carboniferous rocks of the basin of Arroyo dos Ratos, Rio Grande do Sul, which show that the rocks are there decayed to a depth of 318 feet in one place and 393 in another.†† This last is the greatest depth of the decomposition of rocks in Brazil actually recorded.

Hussak says the plateau of schist about Catalão, in the southeast corner of Goyaz, are "for the most part completely decomposed."‡‡

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* First Report of the Imperial Brazilian Mining Company, 1826, pp. 66, 69, 70, 71.

† Travels in the Interior of Brazil. George Gardner. P. 489.

‡ Twenty-eighth Report of the Directors of the Imperial Brazilian Mining Association. London, 1840, Mining Captains' Rep., pp. 41, 49–53.

§ Thirtieth Report, 1841, pp. 48, 56; Thirty-first Report, 1841, p. 35. The reports of this company also contain many general statements and some measurements of decomposition of the rocks at the Antonio Pereira, Cata Preta and other mines. First Report, 1826, p. 16; Second Report, 1826, pp. 52, 53.

|| Travels in Interior of Brazil. George Gardner. London, 1846, p. 493.

¶ Expedition dans l'Amérique du Sud. Histoire du Voyage. F. de Castelnau. Paris, 1850, i, p. 247.

** L'or á Minas Geraes. M. Paul Ferrand. Ouro Preto, 1894, i, pp. 107, 110.

†† Note on the decay of rocks in Brazil. Amer. Jour. Sci., 3d ser., vol. xxvii, 1884, p. 138. This boring penetrates the underlying gneiss 59 feet, and it occurs to one that this part of the decay may have taken place before the deposition of the overlying sediments. Professor Derby, however, does not think so. On decay of 300 meters said to have been reported by Pissis see foot-note, p. 260.

‡‡ Relatorio parcial da Commissão exploradora do Planalto Central do Brazil. Rio de Janeiro, 1893, p. 112.

In his itinerary in Goyaz Castelnau represents the granite just north of Aldea de Carretão as much altered.*

Liais, who traveled extensively in Brazil, especially in the valley of the São Francisco, says that it is no uncommon thing to find places where the gneiss is changed to clay to a depth of more than 100 meters.† The deep decay of the rocks has been noted in the state of Matto Grosso by the writer, and also by Dr Severiano da Fonseca. ‡

In the state of Bahia the crystalline rocks everywhere show the effects of decomposition. In Sergipe and Alagôas the decay of the gneiss and granite which lie inland from the Cretaceous sediments which border the coast is more marked than that of the sedimentary rocks. The schists along the lower Rio São Francisco are much affected locally, some of them decaying much more rapidly than others.

In the state of Pernambuco the rocks are mostly granites and gneisses, and these are deeply decomposed, especially near the coast. The enormous cuts on the Recife à São Francisco railway are almost all in decayed granites. Similar decomposition (though not so deep cuts) and many exfoliated blocks are shown at a number of places in crossing the mountains from Palmares to Bonito and in the vicinity of the latter place. From Pão d'Assucar on the Rio São Francisco to Aguas Bellas the granites are sometimes deeply decayed, especially in the valleys, and boulders of decomposition are common everywhere through the gneiss and granite region lying inland from the schists and sedimentary rocks.

In the state of Pará the older rocks are found in place only away from the river or from the main axis of the Amazon valley. They usually appear at the fall line in ascending the affluents of the Amazon. At the rapids first encountered in ascending the Araguary on the north side of the valley the rocks are granites and are everywhere deeply decomposed and weathered into exfoliated boulders.

Agassiz often refers to the widespread decomposition of the rocks of Brazil. In one place he speaks of them being "reduced to the condition of a soft paste, exhibiting all the mineralogical elements of the rocks as they may have been before they were decomposed, but now completely disintegrated;" § but though he makes frequent reference to the widespread decomposition of the rocks he gives but few measurements of the actual depth to which he found it to extend. In one place he speaks of

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[*] Expedition dans l'Amérique du Sud. IVme partie. Itineraire et Coupe Géologique. Planche 12.

[†] Climats, Géologie du Brésil. E. Liais. Paris, 1872, p. 2.

[‡] Viagem ao redor do Brazil. Rio de Janeiro, 1880, vol. i, pp. 27, 323, 356, 381.

[§] On the drift in Brazil. L. Agassiz. Amer. Jour. Sci., 2d ser., vol. xl, 1865, p. 389. A Journey in Brazil. Professor and Mrs. L. Agassiz. Boston, 1868, pp. 86–89, 400, 401. Atlantic Monthly, vol. xviii, July, 1866, p. 50.

the drift (much of this decayed material Agassiz regarded as of glacial origin) as attaining a thickness of 162 feet.*

Absence of decomposition.—It is worthy of note that in certain arid regions of Brazil decomposition has not been nearly so deep as it has been in the forest-covered parts. This is a striking feature of surface geology in the Cretaceous and Tertiary regions of northeastern Brazil.

Beginning in the high Tertiary plateau of the interior of Bahia and including much of Sergipe, Alagôas,† Pernambuco, Parahyba, Rio Grande do Norte and Ceará, ‡ the soil is, for Brazil, remarkably thin in many places, especially in the more elevated campos, where the rocks are clayey and the drainage is rapid. Spix and Martius must have been impressed by this fact, for they were of the opinion that the soil had been removed by wave-action (*Meerfluthen*) from much of the area. §

The campo region of the Tertiary rocks about Eréré and Monte Alegre, on the Amazon, Hartt found destitute of soil. ||

One of the noteworthy features of this decomposition, wherever it occurs in Brazil, is that it does not penetrate the rocks everywhere alike, even when they are massive and apparently homogeneous.

Mr Darwin noted that the " decomposition did not appear at all conformable with the present undulations of the surface," ¶

Decomposition proceeds along joints and other planes of weakness, and as it penetrates to greater depths undecayed masses are left behind in the shape of boulders of decomposition.

I have no doubt that decay is greatly hastened by the localization of conditions favoring rock decay, and in the main the generalizations of Pumpelly ** and of Gilbert †† in regard to the action of plants hold good, though there are many exceptions to such a rule.

The unequal resistance of certain great bands of gneiss is well illustrated in the flat-sided peaks about Theresopolis, which form the organ pipes of the Organ mountains.

In deep mines and tunnels this selective action is shown by occasional beds of soft materials in the midst of hard ones. In the Morro Velho mines such a soft bed was struck at a depth of 755 feet, after the shaft

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*Sur la géologie de l'Amazon. MM Agassiz et Coutinho. Bul. de la Soc. Géol. de France, 1867-'68, xxv, p. 687.

†See also Der Sertão der Provinz Alagôas u. Die Fälle des Paulo Affonso. Rio de Janeiro, 1880, pp. 30, 31.

‡Trabalhos da Commissão Scientifica, i. Rio de Janeiro, 1862. Rel. da Secção Geologica. G. S. de Capanema, cxxv.

§Reise in Brasilien, iii, 1873.

||Contributions to the geology and physical geography of the Lower Amazonas. Ch. Fred. Hartt. Bul. Buffalo Soc. Nat. Sci., 1874, p. 211.

¶Geological Observations, p. 428.

**Amer. Jour. Sci., 3d ser., vol. xvii, 1879, p. 137.

††Geology of the Henry Mountains, p. 119.

had penetrated over 600 feet of hard rock.* Mr Chalmers, the present superintendent, writes me that while the rocks in these mines are decomposed in places to a depth of 180 feet, he has cut "the mineral at one point only a very few feet below the surface, and it was not in the least affected."

Hunt is of the opinion that where the rocks are deeply decomposed it is simply because the soft materials have not been removed, and "that present climatic differences have nothing to do with the fact that similar rocks are in one area covered with a thick layer of the products of decay, and in another are wholly destitute of it."†

It is not my purpose to discuss this question. It certainly goes without saying that rock decay has been going on ever since land and water existed and that the Paleozoic and other rocks overlying the crystalline rocks of Brazil were formed from the residua of these original foundation rocks of that part of the world. Where the Tertiary beds are seen resting against the granites, near the mouth of the Rio Formoso, state of Pernambuco, the granites are decayed, but it cannot be said positively whether that decay took place before or after the deposition of the Tertiary beds. At the base of the Serra d'Itabaiana the Paleozoic (?) beds rest upon gneiss, which is softened in some places and in others it is not, while the overlying sediments are quite hard. But it is to be expected that in passing through the beach condition the soft clays produced by decay of the underlying gneisses would be pretty completely removed.

Land-slides.—An evidence and result of the widespread and profound decay of rocks in the mountainous regions of Brazil is the prevalence of land-slides. Land-slides are much more common in that country than in the temperate regions. These slides are common all over the country, but they are especially so in the regions of crystalline rocks of the Serra do Mar. They are more frequent along railways and about cities, where the removal of earth at the foot of the slopes has disturbed somewhat the natural equilibrium. They are by no means confined to such places, however, but occur also in the remote forests. Such land-slides were formerly of more frequent occurrence in and about cities than they are nowadays, for the following reasons: The decomposed rock, when dry or not unusually wet, has sufficient cohesion to stand in vertical cuts 20 or 30 feet or more in depth. Before experience was had of the untrustworthy nature of such excavations they were frequently made in the sides of decomposed hills and houses were built in or near them.

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* Forty-second Annual Report Saint John del Rey Mining Company, pp. 5 and 9.

† The decay of rocks geologically considered. T. Sterry Hunt. Amer. Jour. Sci., vol. xxvi, 1883, p. 190.

Brackenridge says, in speaking of the mountains about Rio:

> "They sometimes let loose upon the valleys what is even more dreadful than the avalanche; huge masses of earth, loosening from the rock by the moisture insinuated between them in the rainy season, slip down and overwhelm everything below. It is not long since an instance of this kind occurred, when more than 50 families were buried alive." *

Liais says that in March, 1859, a violent rainfall (14 centimeters in two hours) caused a great land-slide on the Morro do Castello in Rio de Janeiro † and at a great number of places on the east side of the bay.

In 1866 several houses are said to have been overwhelmed by a land-slide near Petropolis.‡ In 1881 I was told by a German living at Petropolis that one of the reasons the German colonies established there had never succeeded was that the hillsides they tried to cultivate were so given to sliding.

Caldcleugh mentions "a space of hardly less than three acres" having slipped from its original position at the old topaz mines near Ouro Preto, state of Minas Geraes. §

On the railways through the mountainous regions land-slides are necessarily superinduced by the cuts where the binding offered by the roots of plants and the support of the natural slope of the decomposed rocks have been removed. The torrential rains precipitate some of these slides every year, though they are now less common than formerly, owing to the care exercised by engineers to prevent them. In some places the cut for the roadbed so disturbed the slope above, that the line of the road has actually been changed in order to evade the constant slipping of the earth upon the railway track.

In tunneling for the Central (formerly the D. Pedro II) railway on the Serra do Mar—

> "Constant danger and difficulty arose from the breaking in of the rock, and in one instance the whole mountain spur through which the tunnel had been driven parted from the main mass and sliding down obliterated the work, so that it was necessary to begin the perforation again." ||

A good idea may be had of the great number of slides along the railways in a single month from an article by Dr J. A. dos Santos published in Rio in 1880. On the São Paulo lines all trains were stopped except on two roads; on the Ituana line traffic was suspended several days; on the English line passenger traffic was suspended for three days and freight

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* Voyage to South America performed by order of the American Government in the years 1817 and 1818. By H. M. Brackenridge. London, 1820, vol. i, p. 104.

† Climats, géologie, faune du Brésil. E. Liais. Paris, 1872, p. 13.

‡ Burton's Highlands of Brazil, vol. i, p. 73.

§ Travels in South America. Alexander Caldcleugh. London, 1825, vol. ii, p. 229.

|| A Journey in Brazil. Professor and Mrs Louis Agassiz. Boston, 1868, p. 528.

for two weeks; there were land-slides on the North line, several on the D. Pedro II and on the União Valenciana; several on the Leopoldina; one slip took place on the S. Paulo branch in decomposed gneiss.*

In general the land-slides so common through the Serra do Mar region represent a considerable part of the denudation on account of the great masses of earth moved short distances; they also expose fresh surfaces to the rain and running water and greatly hasten denudation in this way.

Along the coast from Rio de Janeiro to Bahia one sailing near the shore may see here and there great red and yellow spots upon the landscape, caused by the land-slides and barrancas or washes in the decomposed gneiss of that region.

I see no reason for appealing to hydrostatic pressure for the explanation of land-slides, as Burton has done,† or to earthquakes, as Castelnau suggests.‡ They are to be attributed to the profound decay of feldspathic rocks which yield slippery clays and kaolins and to the concentration of a large precipitation.

TALUS AND ITS DECOMPOSITION.

The formation of talus slopes is not so striking a feature of surface geology in Brazil as it is in cold climates. This is probably due to the fact that in cold regions talus is produced chiefly by spalling off and by the freezing and thawing of water in the cracks of the cliffs. Such agencies are wanting or but feeble in the tropics. Spalling off is caused by changes of temperature, as will be pointed out later, but the rock comes away less rapidly than in cold climates, and the tendency for it to disintegrate is more pronounced than the tendency to flake off.

The talus that does accumulate at the bases of cliffs, bluffs and ledges decays rapidly and the slopes are therefore usually soil slopes instead of rock slopes. The rapid decay of these fragments is due to the fact that they expose a larger percentage of their surfaces to atmospheric agencies, and, furthermore, they fall upon a soil supporting a rank vegetation and abundant insect life, whose acids make quick work of their disintegration, while the heavy rainfall removes the residue rapidly. The talus slopes in granite regions that most nearly resemble true rock talus are those near the ocean, where the waves remove the soil at the base. There is a slope of this kind at the south base of the Pão d'Assucar at Rio de Janeiro. Typical talus slopes of Brazil occur along the whole length of the Serra do Mar and of the Serra da Mantiqueira, in the mountains

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* Revista de Engenharia, ii, no. 2, Feb. 15, 1880. The Rio News, Jan. 25, 1880.

† Highlands of Brazil, i, p. 73.

‡ Expedition, i, p. 202.

ENTRANCE TO THE BAY OF RIO DE JANEIRO.

about Bonito, Garanhuns and Aguas Bellas, in the state of Pernambuco, and wherever granites or gneisses form mountains throughout the country.

Some of the best talus slopes of this type at Rio de Janeiro are those at the south base of the Corcovado and at the east base of the Gavêa.

In a few instances I have seen talus slopes in Brazil which more nearly resemble those of cold climates than the ones just mentioned. There are such slopes along the north base of the Serra d'Itabaiana, in the state of Sergipe. The underlying rocks there are gneisses, while the immediately overlying ones are hard, resisting quartzites, and as the beds dip away toward the southeast at an angle of about 30° the fragments of the decaying outcrop roll down the northwest slope. These rocks resist weathering influences sufficiently well to form a true talus slope.

There are talus slopes also at the bases of the phonolite peaks of the island of Fernando de Noronha.* The geology of that island, however, is different from that of most of the Brazilian mainland, while the encroachment of the sea tends to remove the soil and to keep the surface rocks fresh.

EXFOLIATION.

In general.—Where massive crystalline rocks are openly exposed they decay at the immediate surface and they also break up by a process of exfoliation. These processes produce characteristic forms, both for the rock fragments, large and small, and for the peaks and exposed parts of hills and mountains. These weathered surfaces are of two types, produced by—

a. Exfoliation in concentric layers, leaving rounded surfaces and in some cases sharp peaks. This process affects mountain masses as well as boulders.

b. Disintegration in vertical trenches of rounded sides, leaving the rock surface with a corrugated or fluted appearance.

Exfoliation of peaks.—The topographic forms produced by the exfoliation of openly exposed large masses of granite and gneiss are as a rule so characteristic that they often afford valuable suggestions to the geologist, even at long distances, regarding the nature of the rocks. They are especially serviceable in reconnoissance work along lines of contact between crystalline and sedimentary rocks through the mountainous and thickly wooded regions.

Exfoliated peaks and bosses are so abundant about Rio as to give character to the scenery on every side, and such forms extend up and down the coast and inland almost everywhere that granite and gneiss exist.

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* Geology Fernando de Noronha. Amer. Jour. Sci., vol. xxxvii, 1889, pp. 145–161.

Such hills often have a striking resemblance to some of the great glaciated rock surfaces of the north, so round and smooth are they. Indeed, Agassiz was at one time of the opinion that many of those above Rio de Janeiro were *roches moutonnées.** In other cases they resemble in outline volcanic cones. † Sometimes there is one abrupt, perpendicular, or even overhanging face, while the other sides slope away at a low angle.

The faces of these bare rocks are usually so steep that ordinary vegetation can find no foothold on them, although they are usually beautifully adorned with epiphytes, and especially with little gray bromelias, bearing white and pink flowers. Toward the summits on these rocks the lower angles of the faces allow a little soil to accumulate, and here hardy ferns and such plants as readily withstand dry weather ‡ quickly gain foothold, while the summits are often crowned with bushes and even with large trees. The distribution of these topographic forms corresponds in the main with the distribution of the granites and gneisses, and I have never seen them in rocks of any other kinds.

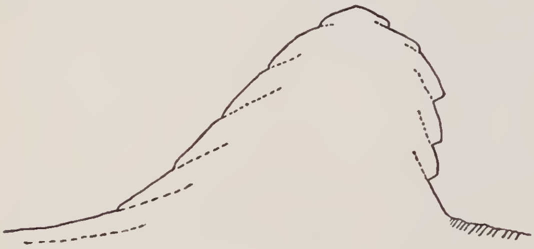

FIGURE 1.—*Diagram illustrating the Exfoliation of Cones.*

It is a noteworthy feature of this exfoliation of peaks that the flakes come to a feather edge on the downhill side, so that they overlap each other like gigantic scales. This is shown in almost every view of these exfoliated mountains. The accompanying diagram exhibits the theoretic arrangement of these crevices on different slopes. These scales also wrap around the peak, as may be seen in the case of the Gavêa (see plate 12). On the shore at Copocabana, on the other hand, these scales seem to be inverted (see plate 11). This, however, may be a local accident. §

The most striking illustrations of these forms occur in the Serra do Mar. They abound in and about Rio de Janeiro, where they give character to the scenery and make the bay of Rio the most beautiful and impressive harbor in the world. At the very entrance to the bay stands the Pão d'Assucar, a solid mass of gneiss more than 1,200 feet high, and rising on one side straight from the water's edge.

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* Jour. Geol , Nov.-Dec., 1893, p. 768.

† Agassiz: Journey in Brazil, p. 69.

‡ Among the plants quite characteristic of such places are certain large species of *Bromelia* whose equitant leaves serve as receptacles and reservoirs for the rain and dew and thus supply them with abundant moisture even when the soil is almost entirely wanting.

§ I am indebted to Mr Edward S. Benest, of Rio de Janeiro, for the photograph of the Copocabana rock, and for several others illustrating this paper.

FIGURE 2.—*Pao d'Assucar.*

An exfoliated peak at the entrance of the bay of Rio de Janeiro.

The Pão d'Assucar or Sugar Loaf is so steep that it is barely possible to ascend it only on one side—the slope on the right shown in the illustration; on all the other sides it is perpendicular or overhanging (see also plate 10). Its steep sides are covered with little air plants, and the least steep one supports patches of sticky grass (*capim gordura*), and on the summit is a cluster of small trees and ferns.

From the top of the Sugar Loaf the view of the hills and peaks to the west includes almost every variety of topographic form to be found in the gneiss and granite regions of the Serra do Mar of Brazil.

The Gavêa (plate 12) is a flat-topped mountain 2,432 feet high (Homem de Mello), about four miles west of the city of Rio, and might appear to be an exception to the rule that granites and gneisses produce rounded forms; but this is more apparent than real. In general outline the mass of the Gavêa is as much like the other mountains around it as any other peak. It is a mass of gneiss, and the banding is approximately horizontal. The flat top is made by one great bed several hundred feet thick, being a little more resisting than the rest of the mass. This layer has allowed the original top to be entirely removed, but it has protected the lower part of the mountain somewhat.*

The Corcovado is 2,329 feet high, of coarse porphyritic granite at the top. On the south side it falls away almost perpendicularly a clean face of over a thousand feet, while to the northwest its slope is sufficiently gentle to admit of easy climbing. Exfoliation goes on now only on the precipitous face, the other sides being covered with vegetation.

Just east of the Corcovado is a rounded peak which may be taken as a representative of a large number of the exfoliated gneiss hills of the region. It is shown in the middle in figure 3. Here the surface has flaked off in great sheets that have slid down the mountain slopes. The angle has now become so low that vegetation is rapidly encroaching upon the mountain mass from the lower slopes and also from the cluster of trees, bushes and undergrowth that crowns the summit.

It seems invidious to mention any of the less prominent exfoliated peaks about Rio. The Dois Irmãos between the Jardim Botanico and the Gavêa and the one on which the church of Nossa Senhora da Penha stands, however, come to mind as examples worthy of special mention; the latter is near the bay, northwest of the city of Rio. No less interesting and striking are the sharp and lofty but always rounded peaks of the Organ mountains—peaks so slender that they have given name to the mountains in which they occur. The accompanying figure, 4, will tell more of the appearance of one of these peaks than any verbal description.

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* The top of the Gavêa is accessible with difficulty at one point only. The summit is covered by exfoliated boulders. Near at hand it is the most impressive of the rocks about Rio de Janeiro.

EXFOLIATING GNEISS AT COPOCABANA BEACH, RIO DE JANEIRO.

THE GAVÊA.

Aside from the general description of the process of exfoliation by which these forms are produced, it is here in place to give the explanation offered by Agassiz for these particular peaks. He says that the strata of "which they are formed are nearly or quite vertical, and that the harder sets of beds alone have remained standing, the softer intervening beds having been gradually disintegrated."*

FIGURE 3.—*The Corcovado from Botafogo, Rio de Janeiro.*

There are several impressive examples of exfoliated mountain masses in the immediate vicinity of Nova Friburgo, some of which are shown in figure 5.

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*A Journey in Brazil. Professor and Mrs L. Agassiz. Boston, 1868, pp. 486, 490, 492. Geology and Physical Geography of Brazil. Ch. Fred. Hartt. P. 16. Gardner says that at Sapucaia the Rio Parahyba follows the strike of the gneiss. Travels in Brazil, p. 537.

The Serra de Macahé east of Nova Friburgo is characterized by the peaks and cones resembling those about Rio de Janeiro,* while from Petropolis along the União e Industria road toward Juiz de Fora and beyond almost to Sitio (north of the crest of the Serra da Mantiqueira) the domed peaks and exfoliating cliffs give character to the landscape.† The Pedra de Parahybuna, near Juiz de Fora in Minas Geraes, is a fine example of the exfoliation of a massive rock. Dome-like summits are also characteristic of the gneiss and granite areas in the diamond district of Minas.‡

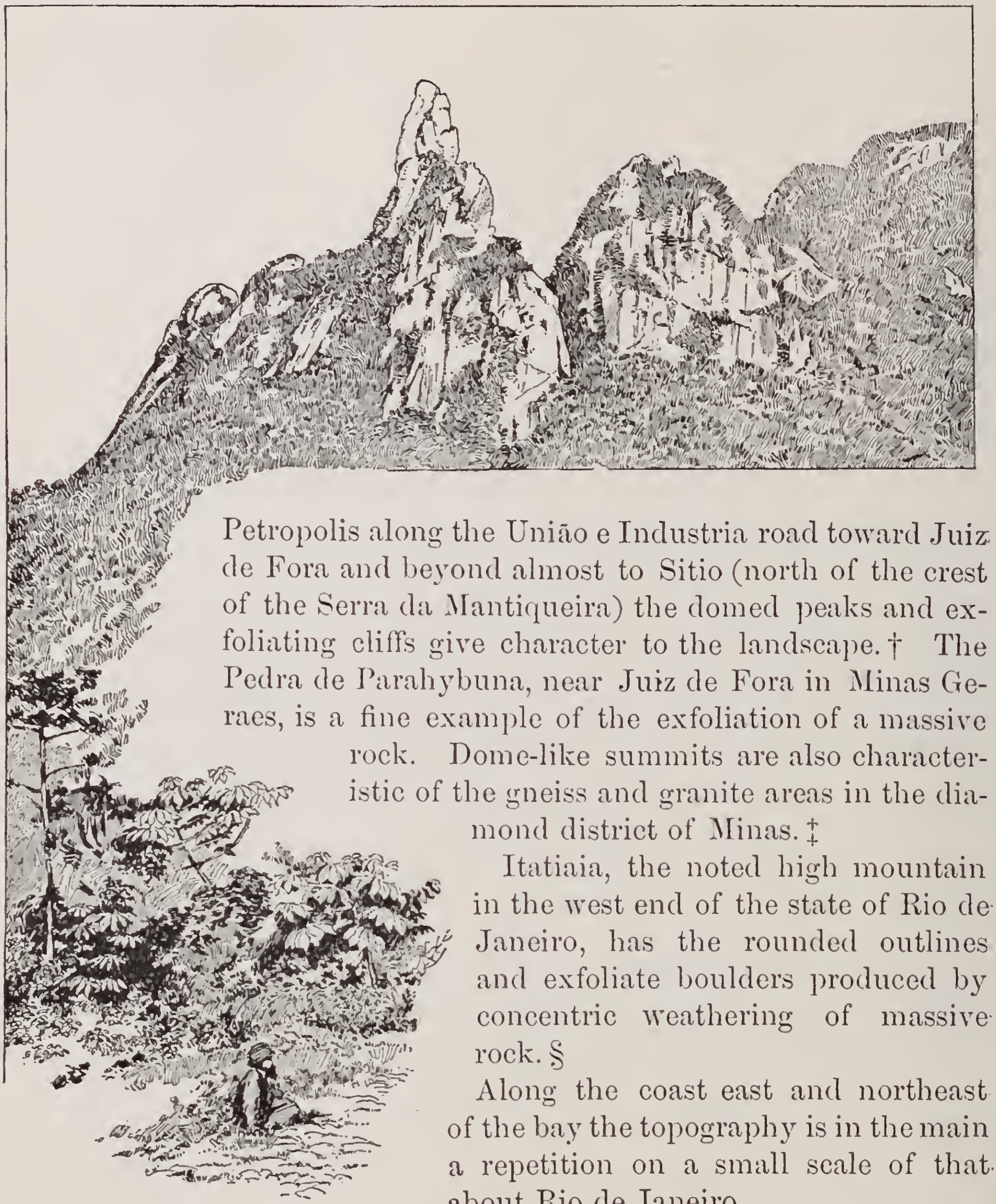

FIGURE 4.—*Dedo de Deus.*

Gneiss peak near Theresopolis, Organ mountains, Brazil.

Itatiaia, the noted high mountain in the west end of the state of Rio de Janeiro, has the rounded outlines and exfoliate boulders produced by concentric weathering of massive rock. §

Along the coast east and northeast of the bay the topography is in the main a repetition on a small scale of that about Rio de Janeiro.

Cape Frio is of crystalline rock (foyite), and though the upper portions are

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* Reise nach Brasilien. H. Burmeister. Berlin, 1853, pp. 139, 177, 178.

† Notes of a Naturalist in South America. John Ball, 1887, p. 314. Bermeister: Reise nach Brasilien, p. 520.

‡ Ueber das Geognostische Vorkommen der Diamanten. Virgil v. Helmreichen. Wien 1846, p. 7.

§ Descripçõo do Itatiaia. Por José Franklin da Silva. Revista do Inst. Hist. do Brazil, xxix, pt. i, pp. 413–418. Excursões Geographicas. Pelo Barão Homem de Mello. Revist Inst. Hist., li, pt. 2, pp. 167–178. Derby says Itatiaia is nephelene syenite instead of granite, as others have stated. Quar. Jour. Geol. Soc., 1887, xliii, p. 457.

FIGURE 5.—*Gneiss Peaks with vertical Ravines, Nova Friburgo, Brazil.*

covered with forests the lower slopes show the usual smooth, exfoliated surfaces.

Nearly all the small islands of gneiss along the coast both north and south of Rio are beautifully rounded by exfoliation.*

On the Parahyba above Campos the hills begin about three miles below São Fidelis, and thence up that stream the exfoliated hills appear here and there far into Minas and São Paulo. Some of the peaks near São Fidelis are especially impressive on account of their height, size, perpendicular sides and their rounded faces. The topography as a whole is strikingly like that at and about Rio de Janeiro.

The great Garrafão south of Limeira, on the northeast border of the state of Rio de Janeiro, is another fine example of an exfoliated peak. It is completely isolated in the plain and has an elevation of 910 meters.† Serra da Onça, about 18 miles north of Campos, is another gneiss peak 1,400 meters in height. Between the Garrafão and the Serra da Onça is one of the most striking mountains of exfoliation to be seen along this coast—the Pedra Liza at the western end of the Morro Bahú. Mouchez gives the elevation of the Pedra Liza as 3,737 feet, and it rises smooth and perpendicular on all sides.

The Serra do Mar continues into the state of Espirito Santo with a vast number of spurs and peaks and exhibiting everywhere the same general topographic features as it does farther south. In the southern part of the state the Serra de Itabapuana has some tall, needle-shaped peaks very much like those of the Organ mountains, some of which are several thousand feet high. The Frade is said by Mouchez to be 6,770 feet high.

At Victoria the church of Nossa Senhora da Penha is built on the summit of an exfoliated peak of gneiss.

Along the Jequitinhonha rounded gneiss hills are abundant from a short distance below Calháo to the Salto Grande on the boundary between Minas and Bahia.‡

There are a large number of conical hills of gneiss at and about the city of Victoria, state of Espirito Santo. Monte Moreno, one of them, is 700 feet high; Pão d'Assucar, another precipitous, almost vertical rock, is about 500 feet high.

Vincent, in describing the country along the Central railway in Bahia, says:

> "Near Tanquinho the hills assumed an appearance similar to those round about the bay of Rio de Janeiro. I saw even a huge rock facsimile of the Sugar Loaf

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* For a sketch of one of the islands of Sant' Anna off Macahé see Hartt's Geology and Phys. Geog. of Brazil, p. 42.

† Les Côtes du Brésil. M. E. Mouchez. Paris, 1876, p. 180.

‡ Hartt: Geol. and Phys. Geog. of Brazil, p. 165.

BOULDERS OF DECOMPOSITION ON PAQUETÁ ISLAND, BAY OF RIO DE JANEIRO.

and another of the table-topped Gavêa. Some great domes of solid rock were visible. . . . "[*]

In the gneiss region of the Pernambuco these rounded forms are common in the mountains west of the city, about Bonito and Aguas Bellas. In the northern part of Brazil, however, these mountains are not so lofty as they are about Rio de Janeiro and south of that city along the coast. In Ceará the rounded and exfoliated hills are common in the gneiss regions also. At and about Quixadá such forms are so common that scores of them may be seen in the immediate vicinity. There is a good example at the end of the great Quixadá dam.[†]

Near Sobral is one of these isolated granite peaks, popularly supposed to be a volcano.[‡]

Mr Darwin [§] suspects "that the boldly conical mountains of gneiss-granite near Rio de Janeiro, in which the constituent minerals are arranged in parallel planes, are of intrusive origin." This arrangement of the minerals is a feature of Brazilian gneiss which is not confined to the peaks alone.

Exfoliation of boulders.—In Brazil boulders of decomposition are characteristic of, and so far as I am aware are confined to, the regions of crystalline rocks. They are common about Rio de Janeiro, where they are sometimes as much as 50 feet in diameter. The noted boulders below the hotel at Tijuca, cited by Agassiz and Hartt in evidence of the glaciation of Brazil, are boulders of decomposition, some of which have rolled down from the mountains above;[||] other large ones lie upon the south side of the Tijuca peak, in the forest. Excellent examples are abundant on the islands in the bay of Rio de Janeiro.

Plate 13 shows some of them on the beach on the island of Paquetá in the bay. There are many other small islands in the bay, especially about the Ilha do Governador, on which they are abundant, while at many places heaps of them appear above water where the soil and softer materials have been removed.[¶] There are similar boulders on the summit of the Sugar Loaf and of the Gavêa; there are many of them about the south base of the Sugar Loaf. There are several very fine ones at the foot of the hills on the east side of Lagôa Rodrigo de Freitas, and others at the south base of the Gavêa. Eschwege records many about

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[*] Around and about South America. Frank Vincent. 5th ed., New York, 1895, p. 313.

[†] The State of Ceará. José Freire Fontenelle. Chicago, 1893, p. 32.

[‡] Trabalho da Commissão Scientifica de Exploração. I, Introducção, Rio de Janeiro, 1862. Relatorio da Secção geologica. G. S. da Capenena, cxxxix.

[§] Geological Observations, p. 468.

[||] Agassiz: Journey in Brazil, p. 86. Hartt: Geology and Phys. Geog. of Brazil, pp. 28–30. Branner: Jour. of Geol., vol. i, 1893, p. 764.

[¶] See also Reise nach Brasilien. H. Burmeister. Berlin, 1853, iii, p. 112. See also South American Sketches. T. W. Hinchliff. London, 1863, p. 224.

Angra dos Reis, in the southern part of the state of Rio de Janeiro.[*] Mr Darwin speaks of having seen at Rio "large sized boulders of greenstone."[†]

In the region northeast of Rio they are locally abundant from the bay to Bahia, varying in size from a few inches to more than fifty feet in diameter (see plate 14). They are more abundant in the mountainous and hilly regions, but they are not confined to them.[‡] Some enormous blocks, 25 or 30 feet in diameter, have been cut through in building the highway and railway from the foot of the Serra to Petropolis.[§] Here and there they have been left perched upon points and ledges by the decay and removal of the rock from about them.[||]

Many striking illustrations occur at and about Itatiaia, in western Rio de Janeiro. A beautiful example is figured by Homem de Mello at this peak.[¶] Along the line of the Pedro Segundo railway they may be seen all the way from Rio de Janeiro to near Barbacena. In the interior of Minas similar boulders are found wherever the granites, gneisses or other crystalline rocks occur.[**] They are abundant along the valley of the Parahybuna, both in Minas and Rio de Janeiro; on the Serra das Aboboras near Parahyba do Sul;[††] on the southeast spur of the Serra de S. Geraldo near Ubá, in southeastern Minas;[‡‡] on the summit of the ridge north of S. João Baptista near Oliveira,[§§] and also between Trigueira and Bom Dispacho.[||||] In Goyaz there are enormous blocks of gneiss between Ciganos and Estalagem, in the valley of Rio Santa Thereza,[¶¶] Central Goyaz.

In the state of Paraná, at the port of Paranagua, the telegraph-signal hill above the village of Cutinga is of granite and has many large boulders of decomposition on and about it. They flank the Morro da Penha at Victoria.[***] There are great numbers of granite boulders at the falls of the Jiquitinhonha, on the border line between Bahia and Minas,[†††] and

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[*] Beiträge zur Gebirgskunde Brasiliens, p. 31.

[†] Trans. Geol. Soc., 2d ser., vol. vi, 1842, p. 427.

[‡] Reise nach Brasilien. H. Burmeister. Pp. 184, 185, 212, 213. Agassiz: Journey in Brazil, pp. 101, 486, 488, 491, 493. Reise in Brasilien. Spix u. Martius, München, 1825, i, p. 166. Travels in Brazil, i, p. 249.

[§] A photograph of one of these blocks is reproduced in Dent's "A Year in Brazil," p. 424.

[||] Keller-Leuzinger's Amazon and Madeira Rivers, p. 48; Burton's Highlands of Brazil, vol. i, p. 64.

[¶] Excursões geographicas. Revist. de Inst. Hist. do Brazil, li, pt. 2, pp. 167, 178; xxix, pt. i, pp. 413–418.

[**] See also Helmreichen's Geognostische Vorkommen der Diamanten, pp. 5, 7, 12, 16.

[††] Gardner's Travels in Brazil, p. 521.

[‡‡] Beiträge zur Gebirgskunde Brasiliens. W. L. von Eschwege. Berlin, 1832, p. 186.

[§§] Beiträge zur Gebirgskunde Brasiliens. Joh. Em. Pohl. Wien, 1832, p. 26.

[||||] Expedition dans les parties centrales de l'Amérique du Sud. Francis de Castelnau. Paris, 1850, i, pp. 376, 378, 311.

[¶¶] Op. cit., ii, pp. 84–86.

[***] Geology and Physical Geography of Brazil, p. 70.

[†††] Travels in Brazil. Prince Maximilian. London, 1820, pp. 302, 304, 306.

BOULDERS OF DECOMPOSITION NEAR RIO DE JANEIRO.

on the Serra do Mundo Novo, near Rio Pardo, about 100 miles west-southwest of Ilheos, Bahia.*

Between Rio do Peixe and Joazeiro, in Bahia, the ridges and flanks of the Serra do Rio do Peixe are strewn with "gigantic isolated boulders of gneiss of peculiar forms."† Morro do Lopes, between Bahia and Joazeiro, is capped by gigantic rounded boulders.‡

At Boqueirão, on Rio Grande, in the western part of Bahia, there are many huge gneiss boulders of decomposition.§

In the interior of Sergipe and of Alagôas boulders of decomposition are formed from the Paleozoic (?) mountain ranges of Itabaiana and Marába inland as far as the gneiss extends. From Pão d'Assucar, on the Rio São Francisco, to Aguas Bellas, in the interior of Pernambuco, gneiss is the prevailing rock, and the boulders of decomposition are abundant and vary in diameter from a few inches to 15 feet and more.||

In Pernambuco there are many examples along Rio Formozo, northwest of the Tertiary sediments. They are abundant near the coast wherever the sedimentary beds have been removed from the underlying granites. In the mountain regions north and west of Palmares they are abundant and very large. In the state of Parahyba do Norte I did not reach the gneiss belt, but the description of the rocks by Williamson leads one to believe that the geology of that state is in nowise different from that of Pernambuco.¶

The "rocks of remarkable forms" seen by Koster near Açu, in Rio Grande do Norte I take to be boulders of decomposition.**

There are gneiss boulders near the base of the Serra dos Cariris in the southwestern part of Ceará and along the Serra Vermelha, in the eastern part of Piauhy.††

The only observations I have been able to make upon the subject in the valley of the Amazon were made at and above the falls of the Araguary, northeast of Macapá. At that place the granites have broken up into boulders, all of which are rounded by exfoliation. They occur at Pedreira near the junction of the Rio Negro and Rio Branco.‡‡ A little below Moura the islands and boulders in the Rio Negro are all rounded.§§

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* Voyage au Brésil. Prince Maximilian de Wied-Neuwied. Paris, 1822, iii, pp. 61, 63.

† Spix u. Martius: Reise in Brasilien, ii, p, 722.

‡ Theodoro Fernandes Sampaio: Revista de Engenharia, vi, 1884, p. 53.

§ Three Thousand Miles through Brazil. J. W. Wells. London, 1886, vol. ii, p. 69.

|| American Naturalist, Dec., 1884, p. 1189.

¶ Geology of Parahiba and Pernambuco gold regions. E. Williamson. Trans. Manchester Geol. Soc., vol. vi, pp. 113-121.

** Travels in Brazil. Henry Koster. London, 1817, vol. i, p. 141.

†† Travels in Brazil. George Gardner. Pp. 232, 237, 238.

‡‡ Journey in Brazil, p. 418.

§§ Spix u. Martius: Reise in Brasilien, iii, p. 1294.

There is "a confusion of rounded blocks" of diorite produced by concentric decomposition at Praia Grande on the lower Tocantins.*

At Ereré boulders of diorite are abundant.† These were mistaken by Agassiz for glacial boulders.‡ The sandstone blocks at the Serra de Ereré are also rounded by decomposition. One great block, 50 feet high, caps the summit of the mountain on the north side.§

FLUTING.

Fluting is a peculiar method of surface decay by which granites or gneisses are left with a corrugated or fluted surface. I have seen several examples of this kind of weathering, but the only ones of which I have notes are in the state of Pernambuco. One of these is in the southwestern part of the state, on Engenho Trapiche, between the mouth of Rio Formozo and the village of Serenhaem. This is a large subangular fragment of granite. One side contains a dozen of these little channels, from 1 to 4 inches deep and from 3 to 10 inches apart from center to center. These channels run straight down the face of the rock.

The other example is on the public road leading from the railway station at Palmares to Bonito, state of Pernambuco. The granite block in which it is best shown is about 40 feet high. This block is fluted in the same way as that near Serenhaem, but the grooves are somewhat wider. In both cases the fluted boulders are openly exposed to the sun.||

There is another form of disintegration somewhat resembling fluting, yet decidedly different from it. In this case the massive rocks are cut by straight-sided channels or ravines varying in depth from a few inches to more than 100 feet. These grooves run straight down the mountain faces. Good examples of them are shown in figure 5, page 275.

AGENCIES OF DECOMPOSITION.¶

The agencies which produce the widespread rock decomposition in

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*A contribution to the geology of the Lower Amazonas. O. A. Derby. Proc. Amer. Phil. Soc., vol. xviii, 1879, p. 164.

†Amazonian drift. Ch. Fred. Hartt. Amer. Jour. Sci., 3d ser., vol. i, 1871, pp. 294–296.

‡Tertiary basin of the Marañon. Ch. Fred. Hartt. Amer. Jour. Sci., 3d ser., vol. iv, 1872, p. 58.

§Contributions to the geology and physical geography of the Lower Amazonas. Ch. Fred. Hartt. Bul. Buffalo Soc. Nat. Hist., 1874, p. 216.

|| Professor Derby has told me in private conversation of having seen boulders similar to these at and about the Serra de Itatiaia.

¶ I have not undertaken to discuss the suggestion of Mr Darwin that the decomposition of the rocks in Brazil occurred under the sea. (Geological Observations. 2d ed, London, 1876, p. 428.) The agencies evidently in operation are competent to account for the work done. Besides, it is not clear to my mind by what process such extensive decay could take place beneath the sea. The zeolites and other minerals dredged up from the ocean are supposed to indicate such action by sea water, but I know of no reason why such minerals might not be dissolved from organic remains as they sink to the bottom.

Brazil are of two general classes, namely, mechanical and chemical. These will be taken up in their order.

MECHANICAL AGENCIES.

General discussion.—The chief mechanical agencies are—

1. Changes of temperature;
2. The penetration of the soil by plant roots;
3. The burrowing of animals.

It has already been shown that over a large part of Brazil rock decay has gone so far, especially in the parts of the country covered by a strong vegetation, that the hard rocks are not now within reach of the roots of plants, and where they are thus accessible the action of the roots is, so far as I know, similar to that of plants in other countries. In any case, the second and third of these are simply contributory in their operation and will be considered under the head of chemical agencies.

A fourth mechanical agency is that of water, as waves or running streams; but while the waves along the coast and the running streams do much mechanical geologic work they contribute comparatively little to the mechanical destruction of the rocks in general.

The immediate mechanical effects of changes of temperature upon a rock are to produce expansion and contraction. I observe, also, that the mica in the Brazilian gneisses (and the same is true when any other mineral constituent forms bands) is an element of weakness, tending both on account of its low conductivity and its form to develop crevices along which the rocks exfoliate more readily.*

Before entering upon the discussion of the action of change of temperature I would call attention to the following facts: The unequal contraction and expansion of the minerals composing the rock tend to disintegrate the entire mass, while the even annual and diurnal changes and the approximately even penetration of these changes cause the rocks to exfoliate or to spall off in layers of even thickness, like the coats of an onion, while the crevices opened in the rocks admit acids and gases and set up a train of reactions that sooner or later disintegrate and decompose the entire rock mass.

I have frequently observed that the decay of rock masses begins along joints or cracks, from which it spreads in every direction. The cause of these joints must therefore be of vital importance to the rock.

The exfoliation of mountain masses and of boulders such as are here described takes place and can take place only when the rocks are massive and more or less homogeneous. Bedding planes and joints are lines of

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* It is usually supposed by those who have but little or no acquaintance with it that gneiss does not make good building stone on account of its banded structure. This is a mistake. The cities of Rio de Janeiro and Bahia are almost entirely built of gneiss, and a finer building stone, so far as durability is concerned, it would be impossible to find.

weakness along which the agents of disintegration and decomposition penetrate. If the massive rock be jointed, boulders of decomposition may still be formed, but the proximity of the joints determine the sizes of the boulders produced by exfoliation.

The process of mechanical breaking up of rocks in Brazil is different from that in operation in cold climates.

In Brazil frost, of course, has no part in the disintegration of the rocks. It is generally supposed that the action of frost greatly facilitates rock disintegration. While this cannot be questioned with regard to steep-faced declivities and hills with high slopes and with regard to the breaking up of the upper three or four feet of the ground, the action of frost through our long northern winters is protective rather than otherwise, preventing the penetration of water and of the dissolving agents it usually carries. Snow is especially protective on account of its preventing radiation, or, as Rozet says, it "acts as a screen between the soil and space."* Frost, moreover, is active only where there is freezing and thawing, not where there is one freeze in the year, as there is in high latitudes. On the other hand, the change of temperature in the tropics is, in the main, a diurnal variation, while in the temperate regions the marked change is an annual one. The diurnal changes of the tropics necessarily take place within narrow limits, while the annual changes in the temperate zones are between extremes that are wide apart.

The tendency of the tropical temperature changes is to affect the rocks to shallow depths and very rapidly, while the slow annual changes affect them more profoundly but much less rapidly; but in the tropics the sun at noon never sinks low on the horizon and the range of temperature is necessarily smaller than that of the temperate regions.

The total annual range of temperature for rocks in the northern part of the United States is from 150 to 170 degrees Fahrenheit, while the daily range in Brazil is only about 100 degrees. This comparatively small range of temperature in Brazil at first glance suggests inefficiency, but the rapid radiation and humidity of that climate are important elements in its effectiveness.

Changes of temperature attack the rocks in two ways: first, by the disintegration of the mass; and, second, by causing exfoliation.

Temperature and disintegration.—Theoretically, incipient disintegration, in so far as it is caused by changes of temperature alone, penetrates as far as do these changes. So long as the rock is homogeneous disintegration caused in this way must penetrate the rocks in parallel planes corresponding to isothermal planes. These isothermal planes are only rudely parallel to the rock surfaces, both in the case of large mountain

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* Comptes Rendus, 40, 1855, p. 299.

masses or of boulders, either large or small. Extreme changes of temperature take place only at the surface, and disintegration due to them must be most rapid there; but, however slight the changes may be, they cannot go on among the heterogeneous materials composing the rock without causing them to slip back and forth against each other, thus producing a mechanical loosening and disintegration of the entire mass.

The component minerals of a crystalline rock contract and expand at different rates at different temperatures. Even in a single crystal the contraction and expansion vary with its different axes, while the irregular arrangement of these crystals in the rock tends to loosen up the whole mass.

In order to comprehend the effect of varying temperature upon rocks it is necessary to know of what minerals the rock is made and the coefficients of expansion of these minerals on their different axes within the range of temperatures to which the rock is subject.

The gneisses about Rio vary a good deal locally in their composition. In some places they are porphyritic, in others they are very fine grained; in some places one of the constituent minerals is in excess; in other places, others. Here they are more like granites, and there they are clearly banded in structure. It follows, therefore, that changing temperatures must affect these rocks differently according to their make-up.

Examination of specimens of gneiss from the great quarries of the Pedreira da Gloria, at the foot of the Morro de Santa Thereza, near Rua da Princeza Imperial, show that it is composed of the minerals mentioned in the list below.* These minerals have different coefficients of

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* Description of Gneiss from the Pedreira da Gloria, Rio de Janeiro, Brazil. Collected by J. C. Branner.

The gneiss is an excellently banded rock, and cleaves across the laminations almost like slate. The banding is due to the alternation of quartzose layers with others more feldspathic. It is readily seen microscopically, and the slides bear out the inference that the dark colored silicates are comparatively rare. Small red garnets are visible, but only of rounded form.

A slide of a quartzose streak discloses quartz, orthoclase and plagioclase in this order of abundance and a few flecks of brown biotite. The individuals are irregularly packed together; all are allotriomorphic, and exhibit on their edges between crossed nicols the evidences of having been subjected to dynamic strains. The feldspars show undulatory extinction, and the quartzes rims of the color of their edges. Cataclastic structure or fractured edges are also to be seen finely developed. The quartz is abundantly supplied with inclusions, both liquid and gaseous, and an occasional rutile needle is seen. The orthoclase is quite clear and transparent, and microcline is also present. The plagioclase is subordinate. Biotite appears as a few small irregular flakes. Little masses of apatite were noted. But the most interesting of all is the presence of sillimanite. This forms small prismatic crystals, which are sometimes grouped in aggregates of two or three, at other times appear singly. They are about 0.2 of a millimeter broad and 0.5 of a millimeter or less long. The customary parting across the *c*-axis is strongly developed, but the regular cleavages are not shown. The crystals are strongly doubly refracting, and polarize in brilliant colors. The crystals were isolated by means of hydrofluoric acid, and the absence of lime proved, which barred out zoisite. Their strong double refraction distinguishes them from andalusite. They were only seen in the slides from one specimen, where they occur in a quartzose layer. It showed no tendency to form the fibrous aggregates with quartz known as fibrolite and bucholzite. Sillimanite has been noted in North America by J. D. Dana in the gneiss of Manhattan island (Amer. Jour. Sci., expansion, and even the same mineral expands differently along its different axes (excepting in the isometric system, to which none of these minerals belong.)† In the case of quartz, for example, it is known that the angles of its faces change at different temperatures. All this causes a slipping back and forth of the minerals upon each other and the opening of minute fractures that mark the beginning of decay.

The mineral constituents of the gneiss from Rio de Janeiro are quartz, orthoclase, plagioclase, biotite (little), microcline, apatite (very little), sillimanite, and rutile needles (very few).

The breaking up of the rock is also aided to a certain extent by the expansion of minerals upon decomposition and hydration. Of the minerals in the list it has been shown that biotite becomes enlarged upon hydration;‡ for the other minerals it has not yet been demonstrated, so far as I have been able to learn.

Comte de la Hure has stated that the Brazilian diorites increase their volume by at least one tenth, and he has expressed the opinion that the hills of Brazil have increased their height by such hydration.§ Merrill has also expressed the opinion ‖ that hydration causes granite to expand. In neither instance, however, can it be said that the case is demonstrated.

Range of temperature.—Lying mostly within the tropics, the climate of Brazil is necessarily a hot one. The temperature seldom falls below the freezing point even in the high valleys of the Minas watershed. The high angle of the noon sun, it being almost directly overhead the year round, affects the rocks directly.

It is to be regretted that so few systematic meteorologic observations have been made in Brazil; but even among the few recorded there are fewer still upon temperatures in the direct rays of the sun, and it is with these temperatures we have to deal—the maximum and minimum to which rocks are subjected. I am of the opinion that while many changes of temperature will do more than a few, the chief work is accomplished by any change or by any number of changes capable of opening cracks in the rock. We find the rocks decomposing always along joints or frac-

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3d ser., vol. xxi, p. 428), by Hawes in the mica-schist of mount Washington (New Hampshire Surv., vol. iii, pt. 3, p. 216), and by G. H. Williams as a contact mineral in the Cortland series (Amer. Jour. Sci., 3d ser., vol. xxxvi, p. 254), in which relations it is also known abroad. It is also recorded by Zirkel from the Humboldt range, Nevada, in mica-schist (40th Parallel Survey, vol. vi, p. 16). Kalkowsky mentions it in the Saxon granulites, in which occurrence and in the Manhattan island locality it probably more nearly resembles the specimens in hand than in the others mentioned.

I am indebted to Professor J. F. Kemp, of Columbia College, New York, for the above. There is also a general description of Rio gneiss by T. Sterry Hunt in Hartt's Geology and Physical Geography of Brazil, page 550.

† The coefficients of expansion for these minerals do not appear to have been determined.

‡ Quar. Jour. Geol. Soc., Feb. 20, 1889; Geol. Mag., April, 1889, vol. vi, p. 187.

§ Revist do Inst. Hist. do Brazil, 1866, xxix, pt. 2, pp. 422–429.

‖ Bul. Geol. Soc. Am., vol. 6, p. 332.

tures, even though these fractures be too small to be detected by the naked eye. Such cracks are therefore the lines of least resistance along which decay takes place, and once they are opened the work of destruction is begun and will never cease until the rock is completely decomposed. It is for this reason that I lay no special stress upon the frequency of changes. Such changes would, however, be of the utmost importance if they sank below and rose above the freezing point. This, however, does not occur in Brazil.

Temperatures in the sun's rays cannot be adduced from temperatures in the shade, and observations made in the sun's rays, even at the same time and place, vary greatly according to the instruments used and the methods of exposure. Without direct observations we can therefore get only an approximate idea of the changes of temperature suffered by the openly exposed rocks. The total absence of such direct observations is the only excuse for the approximations given below.

In 1876, in the dry interior of Pernambuco near Aguas Bellas, I made some observations to ascertain the difference between the temperature in the sun and in the shade. The weather was sultry, and at the hottest part of the day—between 2 and 2.30 p. m.—the thermometer in the sun, and covered with one thickness of black woolen cloth, registered respectively 40, 48, and 50 degrees higher in the sun than in the shade on the three days on which the observations * were made.

If we assume from this suggestion that the temperature in the sun during the hottest part of the day is 50 degrees, Fahrenheit, higher than it is in the shade, we may use the shade readings to determine the maximum sun reading as given for some of the stations mentioned in the table on page 286.

These observations are, to be sure, very desultory and incomplete at best, but they are the only ones now available. I cannot refrain from expressing doubt about the total range of temperature suggested by these figures. My own observations were made during the cooler part of the year in all cases. Although impressions are not to be trusted for such purposes, I am confident that properly conducted records will show that exposed rocks are subjected, except along the coast, to a change of temperature of considerably more than 100 degrees, Fahrenheit.

We are obliged, however, to confine ourselves, for the present, to the data afforded by this table.

Temperature and exfoliation.—The application of the laws of expansion and contraction of rock masses to the Brazilian gneisses would be simple enough if we had to deal with uniform temperatures; but the tempera-

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* The thermometer used for these observations was an ordinary eight-inch instrument mounted on a black tin frame with a metal back. I have no doubt it required correction, but it was borrowed for the occasion, and the errors could not be determined and corrected.

Total Range of Temperature (Fahrenheit) for exposed Rocks.

(* indicates maximum reading in rays of the sun from direct observations.)

Place.	Maximum.	Minimum.	Variation.	Authority.
Manaus, Amazonas	153	71	72	Revista de Engenharia (1).
Pará	145 (?)	70	75	Wallace (2).
Oeiras, Piauhy	149	....	....	Spix and Martius (3).
Ceará*	115	66	49	Pompeo de Souza (4).
Pernambuco	134	75	59	A. B. Pereira (5).
Bonito, Pernambuco*	146	64	82	Branner.
Aguas Bellas*	145	62	83	Branner.
Piranhas, Alagôas	150	72	78	Roberts (6).
Bahia	145	61	84	Draenert (7).
Rio de Janeiro*	117	70	47	Wilkes Expl. Exped. (8).
Rio de Janeiro	117	46	71	Obs. Astron., Oct., 1883 (9).
Rio de Janeiro	117	65	52	Spix and Martius (10).
Rio de Janeiro*	152	70 (?)	82 (?)	Capanema (11).
Rio de Janeiro*	120	56	54	Caldcleugh (12).
Barbacena*	139	36	103	Dent (13).
Queluz, Minas	136	46	90	D. Pedro II R'y (14).
Pirapóra, Minas	148	45	103	Wells (15).
São Paulo	141	47	94	Com. Geol. de S. Paulo (16).
São Paulo	129	47 (?)	82 (?)	Com. Geol. de S. Paulo (17).
Itú, S. Paulo	139	52	87	Com. Geol. de S. Paulo (16).
Tatuhy, S. Paulo	146	47	94	Com. Geol. de S. Paulo (16).
Campos do Jordão, S. Paulo	127	50	77	Revist. do Obser. Ast. do Rio, 1886, 76.
Curitiba (20 ks. E. of)*	145	....	....	Luther Wagoner (21).
Paraná	150	24	126	Bigg-Wither (annual) (18).
Rio Grande do Sul	135	62	73	Revista Engenharia (19).
Tombador, Matto Grosso*	144	68	76	Branner.
Upper Paraguay	152	45	107	Severiano da Fonseca (20).

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*Melloni has shown that radiation reduces the temperature of some bodies 8 degrees centigrade below the temperature of the air (Amer. Jour. Sci., 1849, vol. viii, p. 47), and that at the ground the temperature is 5 or 6 degrees centigrade lower than it is 4 or 5 feet above it (Compt. Rend., vol. xxv, 1847, pp. 501, 502). It is probable, therefore, that this range of temperature should be increased somewhat.

1. Revista de Engenharia, v, 1883, p. 334.
2. Travels on the Amazon and Rio Negro. Alfred R. Wallace. London, 1870, p. 429.
3. Reise in Brasilien, vol. ii, p. 782.
4. Ensaio Estatistico da Provincia do Ceará. Thomaz Pompeo de Souza Brazil. 1863, p. 60.
5. Observações meteorologicas. Antonio Bernardino Pereira do Lago. Revist. Inst. Hist., 1883, xlvi, pt. i, pp. 61–101.
6. Relatorio de W. M. Roberts sobre o Rio S. Francisco. Rio de Janeiro, 1880, N., p. 7.
7. Meteorologia da parte septentrional da Bahia de Todos os Santos. M. F. Draenert. Revista de Engenharia, 1882, iv, p. 28.
8. U. S. Exploring Exped., vol. xi, Meteorology. Charles Wilkes. Philadelphia, 1851, p. 72.
9. Annaes do Imp. Obser. do R. de J. and Bul. Astr. et Met. de l'Observ. Imp. de R. de J. for 1881–'83. The temperatures are "sans abri," but just what is meant is not explained.
10. Travels in Brazil (Eng. ed.), vol. i, pp. 264, 272.
11. Apontamentos sobre Seccas do Ceará. G. S. de Capanema. Rio de Janeiro, 1878, p. 13.
12. Travels in South America. Alex. Caldcleugh. London, 1825, vol. i, p. 17.
13. A Year in Brazil. H. C. Dent. London, 1886, p. 322, *et seq.*
14. Revista de Engenharia, 1882, iv, p. 125.
15. Three thousand miles through Brazil. London, 1886, vol. ii, pp. 317, 319.
16. Dados climatologicos de 1892 da Commissão Geologica de S. Paulo, pp. 34, 37, 38, 41.
17. Professor O. A. Derby, private correspondence.
18. Pioneering in South Brazil. Thos. P. Bigg-Wither. London, 1878, vol. ii, p. 307.
19. Revista de Engenharia, 1882, iv, p. 100.
20. Viagem ao redor do Brazil. João Severiano da Fonseca, i, p. 204.
21. Private correspondence; observation January 27, 1876.

tures are not uniform, either in area, depth or time, and whatever the surface temperature may be, we know nothing from direct observation of their penetration or variation in the particular rocks under discussion.

The observations of Forbes[*] at Edinburgh, of Quetelet[†] at Brussels, of Bequerel[‡] at Paris and of Malaguti and Duroche[§] show that the high and low temperatures do not penetrate the rocks far.[||] At a depth of three feet the total variation according to Forbes is 15 degrees, at 6 feet it is 10 degrees, at 12 feet it is 5 degrees and at 24 feet it is 1½ degrees.

Curves platted from the data furnished by Forbes and Quetelet show that the annual changes are clearly perceptible only to a depth of about 40 feet.[¶] The temperatures we have to deal with in the temperate regions, therefore, are surface temperatures almost literally; but the depth to which a given temperature penetrates varies with the square root of the period of exposure,[**] and as the rocks are exposed to a pretty even annual temperature, and as the periods during which they are exposed to the high diurnal temperatures are but short, it follows that in Brazil the ranges of 10 and 15 degrees lie still nearer the surface than they do in England.

A set of observations was made in laterites[††] at Trevandrum, India (north latitude 8° 30′ 32″, east longitude $5^h\ 7^m\ 59^s$), with thermometers at depths of 3, 6 and 12 feet.

Forbes concludes from the results obtained by Caldecott "that the phenomena of the propagation of heat into the ground near the equator resemble those of temperate latitudes, though modified in extent and character."[‡‡] It should not be overlooked, however, that Caldecott's observations were practically on soil and not on solid rock.

Some important observations that bear on this subject were made by Messrs Newberry and Julien near Bronxville, New York, in July, 1890, upon a boulder of granitoid gneiss.[§§] The character of the rock treated,

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[*] Trans. Roy. Soc. Edin., vol. xvi, 1849, pp. 189-236. See also vol. xxix, pp. 637-656; vol. xxii, pp. 405-427; vol. xxxv, pt. 1, 1887-'88, pp. 287-312.

[†] Comptes Rendus, ii, 1836, 357; Amer. Jour. Sci., vol. viii, 1849, p. 44; Annales de l'Observatoire de Bruxelles, iv, 1845.

[‡] Comptes Rendus, lxvii, 1868, pp. 1150, 1151; lxxiii, 1871, p. 1136.

[§] Comptes Rendus, 38, 1854, p. 785.

[||] Lectures on some Recent Advances in Physical Science. P. G. Tait. 2d ed., London, 1876, p. 274.

[¶] Examination of the temperature readings suggest that there is a layer between about 33 feet and about 60 feet, through which the slight changes of temperature are constantly endeavoring to adjust themselves.

[**] Theory of Heat. J. Clerk Maxwell. 3d ed., London, 1872, p. 245.

[††] Observations on the temperature of the ground at Trevandrum, in India, from May, 1842, to December, 1845. John Caldecott, astronomer to the Rajah of Travancore. Trans. Roy. Soc. Edin., vol. xvi, 1849, pp. 379-391.

[‡‡] Remarks on the preceding observations. J. D. Forbes. Trans. Roy. Soc. Edin., vol. xvi, p. 392.

[§§] Study of the New York obelisk as a decayed boulder. Alexis A. Julien. Annals New York Acad. Sci, vol. viii, 1893, pp. 93-166. See especially page 155.

the temperature and the time approximate the conditions in Brazil when the rocks are largely granitoid gneiss and where the temperature for rocks openly exposed is often between 140 and 150 degrees Fahrenheit for three or four hours during the day.* Their results show that a mean temperature of 152.2°, Fahrenheit, on the surface of the rock will raise the temperature at a depth of 20 inches 4.7°, Fahrenheit, in 3 hours and 46 minutes. Nothing is known by direct observation of the temperatures of rocks in Brazil at any depth beneath the surface; but assuming that the changes of 10 and 15 degrees take place at the same depth as they do in other parts of the world where observations have been made, let us calculate the expansion of the rock which must be caused at the surface and at depths of 3, 6, 9, 12 and 15 feet. The laws of the expansion of certain rocks are known for ordinary temperatures. Gneiss expands one part in from 187,560 to 228,060 parts for every degree Fahrenheit.† If we take one part in every 200,000 as its average expansion for every additional degree, the linear expansion for a surface of gneiss 300 feet long will be as follows:

Linear Expansion for 300 feet of Gneiss.

Depth in feet.	Temperature.	Expansion.
	Fahrenheit.	*Inches.*
Surface	103°	1.854
3	15°	0.27
6	10°	0.18
9	7° (?)	0.126
12	5°	0.09
15	4° (?)	0.072

It must be confessed that these figures are disappointing, for they lead one to suspect, if they do not show, that exfoliation on account of changes of temperature and where small areas are exposed is not so active an agency in Brazil as the exfoliated peaks and boulders constantly suggest.

It is no uncommon thing, however, for surfaces of rock a thousand feet in length to be exposed, and in such cases there must be great strain between the upper and lower layers. Crevices are also opened which furnish access to the rock beneath for that train of destructive agencies which

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*Lord Kelvin and Mr Murray have shown that the thermal conductivity of rocks is diminished by increase of temperature between 50 and 214 degrees centigrade. (On the Temperature Variation of the Thermal Conductivity of Rocks. Lord Kelvin and J. R. E. Murray. Proc. Roy Soc., vol. lviii, no 349, pp. 162-167.) For objections to these results see Robert Weber in Nature, Sept. 12, 1895, pp. 458, 459. But as Dr Julien's data are taken from direct observations, we need not concern ourselves in the present case with variations of conductivity.

†See also "The Origin of Mountain Ranges." T. Mellard Reade. London, 1886, pp. 109-111; A. J. Adie in Trans. Roy. Soc. Edin., vol. xiii, p. 366. According to the determinations of Lieutenant Bartlett (Amer. Jour. Sci., vol. xxii, 1832, pp. 136-140), an expansion or contraction of one inch would take place in every 167 feet with a change of 103 degrees Fahrenheit.

eventually destroy the entire mass—plants and animals, acidulated waters and gases.

It must be, too, that the slight changes of temperature which penetrate to a depth of 15 feet are more potent than similar changes would be at the surface, for the rocks are there confined and are not at liberty to seek relief in several directions; but whether these changes of temperature seem competent to produce exfoliation there are certain cases which cannot, in my opinion, be explained in any other way.

Where large flat surfaces of gneiss are openly exposed to the sun's rays great flakes or shells are sometimes bulged and lifted away from the cooler mass below. Where roads pass over such places they give forth a hollow sound to the horses' hoofs.

In the stone quarries of Rio de Janeiro these sheets of rocks are sometimes 15 feet thick and are utilized by the quarrymen in breaking out blocks of convenient sizes.* These sheets, however, are more commonly from 2 to 10 feet thick, and they are often as thin as a knife blade.

The thicker masses on peaks and mountain sides generally seem to come to a feather edge on the down-hill side and to cover the upper portion of the hill like a close-fitting cap. The breaking off of the lower edge of these flakes gives rise to a rock form quite common in the gneiss region along the coast. It is shown in figure 1, page 270.

I have said elsewhere that exfoliation is not produced by changes of temperature alone, and the idea that these great layers may have been produced by other agencies has not been overlooked. But the other agencies producing exfoliation are chemical, and I know of no way in which water can get into many of these cracks, and there is certainly no evidence of decay along their edges where they are freshly exposed. Except in this respect, the exfoliation of mountain masses takes place in precisely the same way as that of boulders, large and small.

The process of exfoliation in Brazil is not essentially different from that common in other parts of the world, but it is doubtless hastened and given certain characteristics by some of the peculiarities of a tropical climate. One of the finest examples of this exfoliation is to be seen upon the southeastern face of the Pão d'Assucar (Sugar Loaf) (figure 2, page 271), the majestic peak which stands at the entrance of the harbor of Rio de Janeiro. The last disintegrating layer that has fallen away from this peak has left behind and clinging to its sides a few remnants of its original thickness, the lower surface and sides being broken off squarely.

In cases of exfoliation of large steep-faced masses, such as the mountains about Rio de Janeiro, Theresopolis and Nova Friburgo, the con-

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*One of the best illustrations of this kind of exfoliation I have seen is given in the Twelfth Annual Report of the State Mineralogist of California, 1894, p. 384. The exfoliated sheet of granite worked in the Raymond quarry is from 5 to 15 feet thick.

centric layers come away in large masses, which break up in sliding down the mountain sides and exfoliate at the base, where they look like accumulations of gigantic boulders. Where a single fragment remains behind, as in the case of the southwest side of the Sugar Loaf mentioned, held in place by its upper extremity, and being left free to expand on these sides, it may remain thus suspended a long time, less liable to be broken off than if it were surrounded by other portions of the same layer, which might serve as levers to break it.

It often happens that the concentric mass covering a hill of gneiss or granite has its lower portions broken away, leaving suspended from the upper part of the hill a square-faced mantle-like covering. This covering, in the ordinary process of weathering, has its sharper angles first removed by exfoliation, which is always deepest on these edges, and then this same process gradually removes the greater part of the prominence.

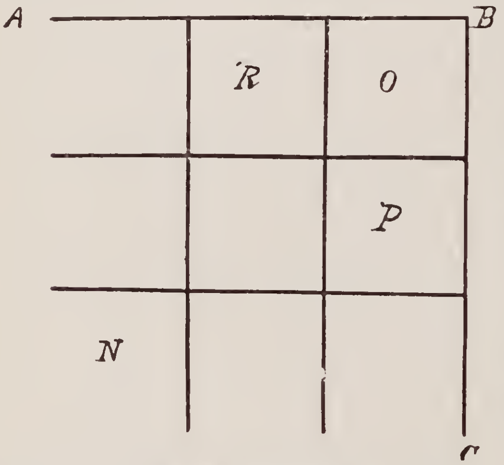

FIGURE 6.—*Diagram illustrating the exfoliating Effect of changing Temperature.*

The rounding of the sharp angles of rocks is due to their greater absorption of both heat and moisture than any equal area of the surface at any other part.

Let *A B C* represent in section the surface of an angular piece of stone. If surfaces of a given size receive amounts of heat equal to x, the surface of R and P would each receive the x temperature, while that of O would receive $2x$, or twice that amount. The resultant of the penetration of x upon O would be in the direction *B N*, and therefore the extra amount of heat in O would penetrate deepest in the direction *B N*.* Except that the process is reversed, cooling takes place exactly like heating—that is, radiation from the angles is greater than from equal bulk at other parts of the exposed faces. It follows, also, that the more acute the angles of the block the greater will be the absorption and radiation and hence the deeper will the isotherm of a given temperature penetrate on the angle.

I endeavored to ascertain whether the obliquity of the solar rays against the surfaces of the granite hills about Rio has made any appreciable difference in their topography. Rio de Janeiro being in south latitude 23°, the sun is to the north during almost all the year. Its rays therefore fall against the north slopes of these conical hills with but little

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* In his Geological Reconnoissance in California, p. 146, W. P. Blake has a diagram illustrating this process of exfoliation by decomposition of sandstone blocks. See also M. Tuomy: Report on the Geology of South Carolina. Columbia, 1848, p. 63.

obliquity, and they therefore attain a higher temperature and might be expected to be modified accordingly. As a matter of fact, the angles of slope of these hills vary greatly and seem to be determined by structural differences, from which it is inferred that structure has more to do with their ultimate topographic forms than has variations of temperature.

It is not to be inferred, however, that the main features of exfoliation are determined by the banding of gneiss, for the sheets come away for the most part regardless of this banding.*

The spheroidal weathering of igneous rocks † is supposed to be due to imperceptible lines of fractures caused by the cooling of the mass and developed by weathering. It should be noted here that there is no reason for supposing that either the mountain masses or the exfoliated boulders of Brazil owe their origin to such action, or that they call for any such explanation.

The exfoliated rocks discussed by Scrope, Mallet and Bonney are igneo-volcanic, while the Brazilian rocks are mostly plutonic. The boulders flake off in the same way, whether the exfoliating masses are broken out naturally or artificially, while there is certainly no reason for supposing that the mountains are cones formed by the cooling of the original mass. The rounding of the hills takes place in precisely the same way as the rounding of any angular fragment of homogeneous rock when its temperature is alternately and quickly raised and lowered.

Professor Shaler has called attention ‡ to the great annual change of temperature suffered by exposed rock surfaces in the northern United States at a variation of about 150 degrees (—30° to 125°+) in half a year, and a diurnal variation often amounting to half that. The annual changes suffered by exposed rock surfaces in Brazil is not so great as this, but, as shown above, it is enough to open the rocks for the penetration of disintegrating agents, which are more active there than in temperate regions. The fact that the changes in temperate regions are lower in the scale is of no importance so long as they do not fall below the freezing point.

Professor Shaler points out in the paper just cited that concentric fracture is the result of changes of temperature, and that it must produce dome-like topographic forms, and that hitherto covered blocks which did not exfoliate before exposure do so as soon as exposed.

Finally it may be said of exfoliation that, while changes of temperature tend to cause it, exfoliation is not produced by changes of temperature alone, and decomposition much less so. I quite agree with the

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* See also geology of New England. T. Sterry Hunt. Amer. Jour. Sci., vol. l, 1870, p. 8.

† Columnar, fissile and spheroidal structure. T. G. Bonney. Quar. Jour. Geol. Soc., vol. xxxii, 1876, pp. 140–154. Geikie's Text-book of Geology, 3d ed., p. 348.

‡ Proc. Boston Soc. Nat. Hist., vol. xii, 1869, pp. 289–293.

opinion expressed by Julien,[*] that the simple heating and cooling of the rock is not, at the temperature it undergoes, a matter of much importance. The importance of such heating and cooling comes almost entirely from the moisture of the atmosphere in which it takes place and from the train of disasters which follow.

What is true of the penetration of heat into the rock mass on a plane surface as compared with that penetrating it on an angle is true also of the penetration of other agents of disintegration, such as carbonic acid and water.[†] This is shown by the fact that the process of concentric decay goes on beneath the surface as well or even better than above ground. Julien found evidences of the penetration of surface waters in micaceous gneiss to a depth of about 10 feet.[‡]

The most important contribution of changes of temperature, therefore, toward rock decomposition is in the opening of crevices for the admission of water and acids which attack the constituent minerals.

Again, exfoliation, whether of mountain masses or of boulders, can take place only with massive and homogeneous rocks. Jointed, bedded, or heterogeneous bodies would admit agents of decomposition unevenly and permit the formation of grooves.

Some reference should be made here to the theory proposed by von Eschwege, who says:[§]

> "The formation of round masses by concentric exfoliation, . . . especially in granite, granite-gneiss and greenstone diabase, depends upon attraction (centralkräften) and the effects of affinity, just as does the formation of strata and as does every regular crystallization. While the entire mass is influenced by the principal force of cohesion which affects the inner layers (centralfächen), this force is also distributed to a small degree along single points in the layers, and exercises its power of attraction in all directions as far outward as its force is not nullified nor hemmed in by the points lying next to it. The nearer it is to the center of this force, so much firmer a nucleus does the rock form; the further away from it it is, so much looser and more scaly does the mass surrounding the nucleus become, and finally, becoming still looser, it passes into a neutral condition until the expression of the force of the next point is seen in the formation of a new globe. In this manner, according as these centers are close together or far apart or have a strong or weak effect, the spheres are larger or smaller, and when of granite (in Portugal, for example, in the neighborhood of Oporto and Penafiel, in the province of Minho), are at times 10, 20 or even 50 feet in diameter; they exist also in oolite of secondary formation as very small spheres.
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> "Our great Werner also considers spheroidal forms, especially those of basalt, as orignal and not as having come from weathering, as several have concluded.

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[*] A study of the New York obelisk as a decayed boulder. A. A. Julien. Ann. N. Y. Acad. Sci., vol. viii, 1893, pp. 93–166.

[†] For the mathematics of exfoliation see Monograph xiii, U. S. Geol. Survey. Washington, 1888. Geology of the Quicksilver Deposits of the Pacific Slope. G. F. Becker. Pp. 68–72.

[‡] Proc. Am. Assoc. Adv. Sci., vol. xxviii, 1879, p. 377.

[§] Beiträge zur Gebirgskunde Brasilien. W. L. von Eschwege. Wien, 1832, pp. 14, 15.

Mr Beudant has proven that the rounded forms in crystallization may be caused by a sudden jar or shock, as may be beautifully shown in a saturated salt solution, which forms genuine globes when the vessel is slightly jarred."

Color as related to decay.—The colors of the rocks of Brazil are a matter of some importance in connection with this subject. It is noteworthy that the natural surfaces of the gneisses and granites are not white, but are of a dark chocolate brown or dark gray color,* colors which absorb and radiate the heat more promptly than would the colors of fresh surfaces, which are all light.

So far as I am aware, scarcely a single dike of basic rock is known in Brazil which is not profoundly decomposed. The diorites and diabases are often found as boulders of decomposition, but the only rocks of the kind which have been reported not so decomposed are the quartz porphyries of the island of Santo Alexio, and these appear fresh only because the decayed rock is removed by the waves as fast as decay takes place.

This more rapid decay is to be attributed in part, I believe, to the dark color of the rock, which causes it to absorb and radiate its temperatures more rapidly than do the gneisses.†

In addition to the temperature effects, it has already been pointed out that the basic rocks are more soluble in acidulated waters than are the acid granites.‡

Texture as related to decay.—The boulders of decomposition are mostly of rather fine grained rock. Coarsely crystalline rocks I seldom saw as boulders, and when they were so found they were comparatively new. These two facts led me to believe that coarsely crystalline rocks were more readily attacked by the agents of decomposition than were the more compact ones. This is also in keeping with my experience of crystalline rocks elsewhere. In Arkansas, for example, the more compact blue syenites seem to be unaffected below the thin coat of decayed rock, while the light gray, coarse grained ones are partially decomposed to a depth of several feet—as far, in fact, as they have been quarried. This is

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* Burmeister notes that all the undecayed granite walls of Brazil are blackened and streaked by water. (Reise nach Brasilien, p. 518.)

† The difficulties surrounding the absorption and radiation of heat and the want of uniformity in methods of observation have prevented my giving specific data on this subject. Actinometric observations were made at the observatory at Rio for a few years, but it is not clear that they are available in the present study, as will be seen from Dr Cruls' description of the apparatus: "The actinometer employed is that of Dall-Eco of Florence, and is composed of two conjugated thermometers of Salleron. . . . One has the bulb blackened with lamp-black, the other is unblackened. Each thermometer is enclosed *in vacuo* in a glass tube." (Bulletin Astronomique et Meteorologique de l'Observatoire Imperial de Rio de Janeiro, 1882, pp. 23, 24.) In March, 1883, the difference in reading between these thermometers ranged from 3.4 to 16.6 degrees centigrade at 9 a. m.; from 4 to 16.3 degrees at noon, and from 0.4 to 16 degrees at 3 p. m. The mean differences during that month were 13.26 degrees for 9 a. m., 13.5 degrees for noon, and 12.17 degrees for 3 p. m. (Annaes do Imperial Observatorio do Rio de Janeiro, iv, 1889.)

‡ Annales des Mines, 7me sér., viii, p. 698.

also well illustrated with certain limestones. The dark, compact limestones have a very thin coat of decayed rock, often not more than a millimeter, while the coarse grained marbles of Tennessee and Arkansas are often affected to a depth of several feet. I suppose this to be due to the greater plane surface of the larger crystals and to the uneven contraction and expansion of these big crystals.

Pumpelly has expressed the same view in regard to rock decay in general.[*] There are a few facts, however, that do not seem to be in accord with this theory. The rock in the summits of some of the high, bold peaks are very coarse grained. Such are the rocks in the summit of the Corcovado and of the Sugar Loaf.

The cause of fluting.—The fluting described on page 280 is produced solely by surface disintegration and removal by rain water. It is comparable to the weathering we sometimes see on very compact and homogeneous limestones. The changes of temperature tend to loosen the immediate surface, and loosening and decomposition are aided by nitric and carbonic acids falling upon the rocks in the frequent hot rains of the country. The water falling upon the rocks tends to flow straight down the surface, and these little channels are simply produced by the removal of the surface as fast as it is loosened.

ORGANIC CHEMICAL AGENCIES.

General discussion.—In the decomposition of rocks in Brazil chemical agencies are vastly more important, more varied and more active than mechanical ones. This is due partly to the enormous quantities of both organic and inorganic acids washed over and into the rocks by the rains, and partly to the high temperature of the waters and acids that attack them. It is important to remember in this connection that the rains are most abundant in that country during the hot season, at a time when the rocks are exposed alternately to the direct rays of a blazing sun and the rains, some of them drizzling and lasting for days; others poured down in torrents.[†]

Whatever chemical agents fall in these rains or are picked up on the rock surfaces are rendered more active by the water being heated by the hot rocks upon which it falls and over which it flows.[‡]

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[*] The relation of secular rock disintegration to loose glacial drift and rock basins. R. Pumpelly. Amer. Jour. Sci., 3d ser., vol. xvii, 1879, p. 136.

[†] Von Tschudi says: "The severe nocturnal downpours followed by oppressively hot days disintegrate even the hard rocks in an extremely short time." Die Brasilianische Provinz Minas Geraes. Gotha, 1862, p. 5.

[‡] Agassiz: Journey in Brazil, p. 89. Poiseuille's Recherches expérimentales sur le mouvement des liquides dans les tubes de très petits diamètres (Comptes Rend., 1840, xi, p. 1048; 1841, xii, pp. 112–115) show that liquids flow through capillaries three times as fast at 113 degrees Fahrenheit as they do at 32 degrees. His later observations show, however, that most of the natural waters are much retarded by the minerals they hold in solution (Compt. Rend., 1847, xxiv, pp. 1076, 1077).

I have frequently observed during rains, especially when there has been a shower on a hot day, that the water flowing from such surfaces is decidedly hot, but I never made any record of its temperature. This temperature can only be inferred from the data given for the temperatures to which the exposed rock surfaces are subjected.

Caldcleugh says, however, that the temperature of water running over these exposed rock surfaces "often reaches 140° or 150° Fahrenheit," and he believes that the silicious stalactites found by him at Rio de Janeiro were dissolved by these hot waters from the gneiss.*

For convenience sake chemical agencies may be classed as organic and inorganic. By far the more important of these are the organic acids which are washed over the rocks and soil and into their crevices. These acids are derived from two sources, namely, from burrowing animals and from plants.

Burrowing animals.—Ants. Most of the burrowing in Brazil is done by ants, termites and other insects.† An important part of the work of these insects is mechanical, but their chemical work is vastly more so. They are found almost everywhere—in fields, forests and campos—though they are much more abundant in some places than in others.

In some of the campo regions of the Amazon valley of Minas, Goyaz and Matto Grosso the soil looks as if it had been literally turned inside out by the burrowing of ants and termites.

Forel says that "the ant fauna of South America is perhaps the richest in the world."‡

I do not know how many species of ants and termites live in the ground in Brazil;§ indeed the number of species is a matter of little or no importance as compared with the number of individuals and their habits, and of this it is impossible to give more than a very general impression. At the time of mating I have often seen the country covered for miles so thickly with young females that they would average an individual to every square yard of surface.

Of the ants proper there is one kind, known in Brazil as *saúbas* or *saúvas*, which deserves special attention.

These ants live in large, often enormous, colonies,|| burrow in the earth, where they excavate chambers with galleries which radiate and

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* On the geology of Rio de Janeiro. Alexander Caldcleugh. Trans. Geol. Soc. Lond., 2d ser., vol. ii, 1829, pp. 69–72.

† Earthworms, which play so important a part in the formation of soil in temperate climates, take no such part in the work in Brazil.

‡ A fauna das formigas do Brazil. Relo Dr A. Forel. Boletim do Museu Paraense, i, 2, p. 89. Pará, 1895.

§ Four hundred and forty species of ants alone are described from Brazil. These are not all burrowers, however. Boletim do Museu Paraense, i, no. 2, p. 142.

|| Azevedo Sampaio estimates some of the colonies at 175,000 to 190,000 individuals, and others at 600,000. Saúva ou Manhú-uâra, pp. 50, 54. São Paulo, 1894.

anastomose in every direction, and into these galleries and chambers they carry great quantities of leaves. One can get some idea of the extent of these openings from the heaps of earth brought up by the insects. These mounds are often from 50 to 100 feet long, from 10 to 20 feet across, and from 1 to 4 feet high,* and contain tons of earth. The underground galleries of the *saúbas* penetrate the soil to great distances. These ants are very injurious to vegetation, and one of the methods used by the planters to kill them is to blow poisonous fumes into their burrows. I have seen these fumes blown into one of these openings issue several hundred, even 1,000 feet, away. Mr Charles J. Dulley, of São Paulo, tells me that he has observed openings 600 feet from the *panella* or chief nucleus. A gallery of equal length on the opposite side would give a horizontal width of their galleries of 1,200 feet. Bates saw *saúba* galleries in the Botanical Gardens of Pará 70 yards long. He says, on the authority of the Reverend H. Clark, that ants tunneled beneath the Parahyba river.† Bates also tells of the fire-ants at Aveyros on the Amazonas actually driving the inhabitants out of that town.

> "The soil of the whole village is undermined by them; the ground is perforated with entrances to their subterranean galleries."

And yet when the young winged ants come from their nests at the beginning of the rainy season they are blown into the river and drowned in such numbers that a "compact heap of dead bodies . . . extends along the banks of the river for 12 or 15 miles." ‡

Clark says: §

> "Brazil is one great ants' nest. They are of all sizes and dispositions: some are a plague to us in the house, for they will come at nights and prey on the insects in our store-boxes; some are a plague to us in the forests, for they get inside one's clothes and bite and sting; others are a more serious evil still—vegetable feeders, which will take a fancy to the leaves of some tree and strip every leaf off in one night. Some species . . . burrow for miles six or ten feet below the surface of the ground."

Another writer says:

> "The multiplication of these insects is so rapid, their retreats so inaccessible, their organization so perfect, and their mandibles so audacious that one seriously asks whether they are not the real conquerors of Brazil. . . . One may see colonists giving way before these indefatigable invaders every day." ‖

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* Wallace mentions heaps from 30 to 40 feet long and 4 feet high. A Narrative of Travel on the Amazon and Rio Negro. Alfred R. Wallace. London, 1870, p. 37. C. Brent mentions a mound 45 feet across and 2 feet high. American Naturalist, vol. xx, 1886, p. 124.

† Naturalist on the Amazonas. Henry W. Bates. 4th ed., pp. 9–15.

‡ Naturalist on the Amazonas, 4th ed., p. 206. See also pp. 350–360.

§ Letters Home from Spain, Algeria and Brazil. Reverend Hamlet Clark. London, 1867, pp. 131, 173. The Zoölogist, May, 1857, p. 5561.

‖ Le Mato Virgem; scènes et souvenirs d'un voyage au Brésil. Adolphe d'Assièr. Revue des Deux Mondes, xlix, i, 1864, p. 582.

The only personal observations I have been able to make in regard to the depth of these excavations were along the line of a canal in the diamond regions of Minas Geraes; there the chambers or enlarged galleries were found from 4 to 8 feet below the surface, the chambers being arranged in tiers or on floors one above the other. Sampaio gives one section through a nest over 7 feet deep and another 11½ feet deep.[*] I have frequently been told, however, of these galleries being as much as 12 feet deep in the old *saúba* colonies, and that the ant-killers on coffee plantations often open them out to this depth.

The Reverend H. C. McCook has described the habits and abodes of a Texas ant (*Atta fervens*) which give some idea of the extent of ant burrows.[†] This species makes its galleries as much as 12 feet in diameter, 15 feet deep and 120 feet long. Belt tells of the leaf-cutters (*Œcodoma*) having galleries 4 or 5 feet deep.[‡]

The Reverend J. G. Wood tells of an instance of *saúbas* having "ruined a gold mine for a time, breaking into it with a tunnel some 80 yards in length and letting in a torrent of water, which broke down the machinery and washed away all the supports, so that the mine had to be dug afresh."[§]

The chambers in the galleries examined by me were all found to contain loose balls made of the fragments of leaves that had been carried in by the ants.[||]

The quantities of vegetable matter carried into their burrows is almost beyond belief. I have seen a full-grown orange tree completely stripped of its foliage within a few hours. In the coffee regions the damage done by them is so serious that the Brazilian government at one time offered a large premium for a successful *formicida* or ant-exterminator.[¶]

I can vouch for the accuracy of the description given by Lund of the work of these ants. The case is quoted here for the purpose of giving

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[*] Saúva ou Manhú-uára. A. G. de Azevedo Sampaio. São Paulo, 1894, pp. 22, 52, 64.

[†] Proc. Phil. Acad. Nat. Sci., 1879, pp. 33–40. Abstract in Annals and Magazine of Nat. Hist., 5th ser., vol. iii, pp. 442–449.

[‡] A Naturalist in Nicaragua, p. 76.

[§] Wanderings in South America. Charles Waterton. London, 1882. Explanatory index. Reverend J. G. Wood, p. 47. *Formigas saúvas*, extracts from an article by Dr G. S. Capanema. Auxiliador da Industria Nacional, xliv. Rio de Janeiro, 1876, pp. 32–36.

[||] On the injury done by ants to crops see the Revista Agricola do Imperial Instituto. Fluminense de Agricultura, ix, 1, March, 1878, p. 21; xiv, 4, December, 1883, p. 215. O Auxiliador da Industria Nacional, xliv, Rio de Janeiro, 1876, p. 31. Tratado descriptivo do Brazil em 1587. Obra de Gabriel Soares de Souza. Revista do Inst. Hist. do Brazil, 1851, xiv, p. 271. See also ibidem, p. 163.

[¶] Belt thinks the leaves carried into the ground by these ants are used to grow fungi for food (Naturalist in Nicaragua, p. 80). The balls of leaves I have seen were all covered by fungi. Burmeister thinks the leaves are allowed to decay and are then fed to the larvæ (Reise nach Brasilien, p. 372). Barão de Capanema says the young ants are fed upon a white mould which is planted and cultivated with care by the ants (Auxiliador da Industria Nacional, xliv, 1876, p. 34). This has now been established by Dr Moeller (Die Pilz-Gaerten einiger Südamerikanischer Ameisen, Jena, 1893. See also Boletim do Museu Paraense, i, no. 2, pp. 90, 91. Pará, 1895).

an idea of the amount of vegetable matter carried into the ground by them:*

> "Passing one day near a tree that stood almost alone, I was surprised to hear the sound of leaves falling to the ground, though the air was calm. . . . What increased my astonishment was the fact that the falling leaves had their natural color, and that the tree seemed to be perfectly sound. I went up to see the reason of this phenomenon, and found on almost every petiole an ant at work with all its might. The petiole was soon cut off, and the leaf fell to the ground. Another scene was going on at the foot of the tree. The ground was covered with ants occupied in cutting up the leaves as fast as they fell, and the pieces were carried at once into the nest. . . . In less than an hour the work was done before my eyes, and the tree stood completely defoliated."

Burmeister says some of the large ants (*Atta cephalotes*) will "strip whole trees in a single day"† and carry the leaves into the ground.

> "A good-sized mango tree, at least as large as an average apple tree, I saw stripped of every leaf in one night." ‡

The following is an account of the *saúbas* in São Paulo: §

> "The enemy most dreaded in the *fazendas* is indubitably the suáva or Tana-júra, a black-brown ant two centimeters long, which undermines the ground by digging extensive passages and dens in all directions. It attacks all sorts of trees, the coffee-shrub among others . . . In former times these ants seem to have worked frightful havoc in the *cafesaes* (coffee fields) by causing land slips, because the means of destroying whole nests at that time was not discovered. Now they are less feared, although it still costs from 8 to 12 guineas a month per plantation to keep them down. On every *fazenda* (plantation) two or three slaves are kept whose exclusive business it is to find out the nests of the *saúvas* . . . The subterranean ant labyrinth destroyed in my presence near the fazenda Areas in Cantagallo seemed to be very extensive."

From a geological point of view the extent of these underground passages, the nature and amount of the materials carried into them and the size of the colonies are matters of importance.

Termites.—Some of the termites or white ants of Brazil (popularly known as *cupim*) live upon wood and build their nests upon the trunks or branches of trees, while others live in and upon the ground and build their houses of clay upon its surface. Here, again, I have not concerned myself with the number of species, for it is the number of individuals and their habits with which we are chiefly concerned. ||

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* Lettre sur les fourmis du Brésil. M. Lund. Ann. des Sci. Naturelles, xxiii, p. 118.

† Reise nach Brasilien, p. 372.

‡ Notes on the Oecodomas or Leaf-cutting Ants. C. Brent. Amer. Naturalist, vol. xx, 1886, p. 124.

§ Brazil and Java. Report on Coffee Culture in America, Asia and Africa. C. F. Van Delden Laerne. London, 1885, pp. 297, 298.

|| Dr J. Barbosa Rodrigues says there are two species—one living on wood and in trees, the other on the ground (Revista do Inst. Hist. do Brazil, xliv, pt. i, 1881, p. 76). Dr Fritz Müller, however, an excellent entomologist, who has lived many years in southern Brazil, says that he has found there 15 or 16 species (O Auxiliador da Industria Nacional. Rio de Janeiro, 1874, xlii, p. 518). Jenaisch Zeitschrift, vii, 1873, pp. 333–358, 451–463. Abstr. An. and Mag. Nat. Hist., 4th ser., xiii, 1874, pp. 402–404. These species do not all live on the ground, however.

How deep the galleries of the white ants penetrate the soil I do not know, and I have not been able to find any record of the observations of others upon this subject.* The size of the nests of clay above ground, however—from 1 to 12 feet in height and from 1 to 10 feet in diameter—is certainly enough to justify the belief that these channels are extensive.

They are not confined to any particular kind of country or soil, so far as I could ascertain, but they are more abundant in some regions than in others. They are especially noticeable on the *taboleiros* and *chapadas* of the interior and in the campo or timberless regions generally, where they are a common feature of the landscape. I am not sure, however, that their abundance in the campos is not apparent rather than real, for even were they equally so in the forests their presence would not be so noticeable.† I have observed them from the state of Paraná to north of the Amazon. Along the upper Paraguay in Matto Grosso I have seen places where the nests are so close together that one could almost walk upon them for several hundred yards at a time, while over many acres of ground no one of the nests was more than 10 feet from another.‡

The *cupim* or termites houses vary much in form. Some of them, as Burmeister facetiously suggests, bear a strong resemblance to gigantic Irish potatoes. They are mostly domed or rounded, but many of those of the upper Paraguay are tall and slender and peaked, and are as much as 6 or 7 feet tall, though not usually quite so high. These tall, slender ones are commonly known as *frades de pedra* or stone friars.§

On the campos of the Amazon valley north of Macapá the nests are usually tall and large. Mr Horace E. Williams, chief topographer of the Geological Survey of São Paulo, writes me that about Taubaté, in São Paulo, these nests are frequently 8 feet high, while about the city of São Paulo they are only 2 or 3 feet high. Over the campos of Minas, Bahia, Pernambuco and the interior generally they vary from 2 to 12 feet in height and from 2 to 10 feet in circumference.||

Mr Charles J. Dulley says he has seen the termites nests about Caxambú, in the southern part of Minas Geraes, as much as 12 feet high and 5 feet across at the base. He tells of a case of one of these abandoned mounds having been hollowed out and used by a baker as an oven.

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* Drummond tells of pits of white ants in the Lake Nyassa region of Africa "some dozen feet in depth." The white ant: a theory. Henry Drummond. Good Words, 1885, p. 303.

† Burmeister expresses the opinion that they are more abundant in the woods than in the campos. Reise nach Brasilien, p. 491.

‡ See also Viagem ao redor do Brazil. João Severiano da Fonseca. Rio de Janeiro, 1880, i, p. 352.

§ The only good picture I have seen of the nests of termites is that given in the Challenger reports and taken at cape York, northern Australia. Narrative of the Cruise, vol. i, pt. 2, pl. xx, p. 532.

|| Travels in South America. Alexander Caldcleugh. London, 1825, ii, p. 194. Voyage dans les Provinces de Rio de Janeiro et de Minas Geraes. Aug. de Saint-Hilaire. Paris, 1830, i, p. 108. Notices of Brazil in 1828 and 1829. R. Walsh. Boston, 1831, vol. ii, p. 51. Reise nach Brasilien. Von Burmeister, p. 491. Reise in Brasilien. Spix u. Martius, ii, p. 719. Voyage au Brésil. Prince Maximilien. Paris, 1822, iii, p. 129.

These termites live partly in their houses and partly in the ground. Their nests all open into the soil beneath, so that the acids and gases produced by these vast numbers of insects are poured into the ground and eventually carried down to the rocks beneath.

The galleries of the ants proper spread out on all sides of the main entrances and anastomose so as to form a vast network of underground channels, into which the ants drag their food and the leaves of plants, where their dead bodies decay, and where their breath so long as they live contributes carbonic acid* to the other organic acids formed by the decay of this animal matter, all of which attack the rocks and soil and are washed by the rains to lower levels.†

One fact which suggests the great numbers of these ants is that there are in Brazil several species of armadillos and ant-eaters which subsist in part or entirely on ants and termites; and the tamanduás or ant-eaters are no small animals. Gardner tells of having killed one that measured 6 feet in length, not counting the tail, and 10 feet with the tail.‡

Chemical work of plants.—The effect of vegetation upon rock disintegration comes from, first, the mechanical effects of penetrating roots, which break up the material; second, making courses or roads of the roots along which the surface waters readily penetrate; third, the abstraction from the earth of such materials as are available in plant growth; fourth, in the formation of acids upon the decay of the plants.

I. The mechanical work of penetrating roots scarcely need be dwelt upon here. Every one is acquainted with the prying off of boards from houses by ivy and Virginia creeper and the lifting of sidewalks by the roots of trees passing beneath them. On a smaller scale this kind of work loosens the earthy particles and opens incipient cracks and even separates large blocks.

II. The second point is well understood by hydraulic engineers and by any one, indeed, who has had occasion to build earth dams. Roots left in the earth beneath the dam are almost certain to guide the water along incipient breaks. It seems to be next to impossible to prevent leaks in ground containing such roots, and for this reason careful engineers always have such grounds cleaned of stumps and roots before fills are made.

III. Besides abstracting a large part of the plant's food directly from the soil, the roots of plants are able to attack and dissolve the rocks them-

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* I know of no determination of the carbonic acid exhaled by ants. Moleschott's researches on the production of carbonic acid by animals relate only to frogs. His results may or may not be applicable to ants. Comptes Rendus, xli, 1855, pp. 363, 456, 961.

† James E. Mills is the only person who, so far as I am aware, has called attention to the geological work of ants (Amer. Geologist, June, 1889, p. 351). It is spoken of by Henry Drummond (Good Words, May, 1885, p. 303), but only the mechanical importance of their work is suggested.

‡ Travels in Brazil. George Gardner. London, 1845, pp. 398, 399.

selves. This direct solvent action of roots and rootlets upon rocks has been practically demonstrated by Sachs.*

IV. But, however important these operations may be, it is to the last agency—the formation of acids by decay—that attention is especially directed.

The richness—rankness—of Brazilian vegetation, except, of course, in the campo region, is almost incredible. If a forest be cleared away and then left to itself it grows up so quickly that in three or four years it looks almost like a primeval forest, except in the cases of a few of the slower growing trees, such as rosewoods, *braúnas* and *perobas.* The forests of the forest regions are literally impenetrable except by the use of the *facão* or big forest knife. Where they are traversed by roads one can often travel for days in a twilight gloom without getting more than occasional glimpses of the sky.

> "Plus on avance dans ces forets, et moins il y a d'ouvertures: on peut y marcher l'espace de plusieurs jours, et le ciel se montre rarement à travers les routes aériennes dont la verdure rĕcouvre le voyageur." †

Mr Clark gives the following graphic description of the forests of the Organ mountains: ‡

> "We were in the deepest shade; some 50 or 80 feet above our heads were the bushy tops of closely packed trees; then below them a second covering of palms, fern trees, and such like, all loaded with parasites; below them again was thick-tangled brushwood, not in the least like our English brushwood, that good naturedly gives way to your arms and hands as you stride through it, but interlaced in all directions with long trailing, creeping plants, some with stems as thick as my wrist, others thinner; the thinnest and by far the worst for us were thread-like runners that were no thicker than string, so tough that to break them was impossible and so long that they would not give way before us. Underneath this monster vegetable net . . . was the ground, covered with masses of dead leaves, broken branches, all the débris of the vast vegetable creation above that had been accumulating for countless ages, and often green with little plants and ferns."

The darkness of these forests, however, is seldom a cool shade; the hot air is reeking with moisture and the conditions highly favorable for plant growth. But while vegetable growth is notoriously rapid and rank its decay is equally rapid, and this decay produces large quantities of organic acids, which are carried by the rains into the soil and the underlying rocks. Even on the barest rock surfaces there is always considerable vegetation in the form of lichens, liverworts and small epiphytes (bromelias). These plants furnish but little protection against the mechanical wearing of the rocks, while they contribute destructive acids to

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* Experimental Physiologie, p. 188; Johnson's How Crops Feed, p. 326; Bot. Zeitung, 1860, p. 118.

† Voyage Pittoresque dans le Brésil. Maurice Rugendas. Paris, 1835, p. 10.

‡ Letters Home from Spain, Algeria and Brazil. Hamlet Clark. London, 1867, p. 123.

the surface waters.* They also help to keep the surface of the rock moist and thus increase the radiation at night and enable the acids to attack the rock. Besides, they color the surface of the rock black or dark brown, and this color causes the rock to absorb more heat than it could otherwise do. It is worthy of note in this connection that vegetation, except upon the bare surfaces, while it hastens decomposition, retards denudation. Scouler says that "in the vicinity of the coast this rock is protected from the influences of the weather by the dense vegetation which covers the soil."† This is true only in so far as it relates to denudation.

It has been pointed out by Corenwinder that the sun shining upon decayed organic matter develops carbonic acid.‡

Decomposition of the rocks seems to take place most rapidly and extensively where drainage is sluggish, denudation but slight and the soil supports a rank vegetation and where the decay of organic matter is most rapid. Water falling upon such a surface is impeded by the vegetation, and, charged with organic acids, it soaks into the ground and performs its work of rock destruction. Hartt was of the opinion that deep decomposition was confined to regions which are or have been covered by forests. He says:

> "I believe that the remarkable decomposition of the rocks in Brazil has taken place only in regions anciently or at present covered by forests." §

Julien expresses the opinion that—

> "Both in Brazil and in our southern states the main agents of disintegration have been mainly derived . . . from neither atmospheric nor subterranean sources, but from the heavy forest-growth which preceded the inroads of her present civilization."

This is a theory which commends itself to every geological observer in Brazil. There are so many instances of deep decay, however, in regions now not forest-covered, and where it is impossible to say positively whether they have ever been so covered, that one is obliged to own that it cannot be either proven or disproven.

It is generally understood that the more watery vegetable substances decay more rapidly. This heavy, spongy and watery nature is characteristic of the greater part of tropical plants, and especially of those forming the undergrowth.

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* On the geological action of the humus acids. Alexis A. Julien. Proc. Am. Assoc. Adv. Sci., vol. 28, 1879, pp. 311–410. How Crops Feed. S. W. Johnson. P. 138.

† The Edinburgh Journal of Science, vol. v, October, 1826, p. 201. Gilbert's statement of the geological influence of vegetation is well illustrated by Brazilian rocks. Geology of the Henry Mountains. G. K. Gilbert. Pp. 104, 105.

‡ La production du gaz acide carbonique par le sol. M. B. Corenwinder. Comptes Rendus, 41, 1855, pp. 149-151.

§ Hartt's Geology and Physical Geography of Brazil, pp. 25, 319.

I know of no determinations of the carbonic acids in the soils of Brazil such as were made by Boussingault and Léwy in France.*

Supposed work of bacteria.—In the original preparation of this paper the work of bacteria in rock decomposition was not specifically referred to because it was supposed to be included under the general head of organic acids derived from the decay of plants. Since the paper was presented I have found that there is an impression abroad that bacteria attack rocks directly, and that they must be the more important in tropical countries on account of their greater activity in warm, moist climates.

It is not possible to discuss this subject at length here, but a brief statement of the principal facts will not be out of place. It was formerly supposed that only the chlorophyl-bearing plants could subsist upon mineral substances, and that organic matter was indispensable to the existence of bacteria. Warming definitely states that "organic carbon compounds are indispensable for all bacteria except, as it appears, for the nitrifying organisms."† In 1886 Frankland began experiments which demonstrated the fact that certain forms of the nitrifying bacteria may live without organic food.‡ Similar results were obtained by Waring, § Winogradsky || and Berthelot. ¶ It cannot be considered as demonstrated from these researches, however, that bacteria are capable of taking their sustenance directly from the rock-making minerals. The solutions used in the experiments in every case contained substances from which the bacteria could derive the nitrogen (and carbon) essential to their existence, such as humic acid, ammonium chloride, or some other form or combination of nitrogen. No such substances occur in the rocks except as they are carried in from the surface, and when so introduced the bacteria which go with them simply take part in the attack made upon the rock constituents by organic acids. It is easy to understand, then, why Muntz found bacteria at depths in "des roches dites pourries," or disintegrated rock;** they were there chiefly as the result of decay, not as the cause of it. In brief, I am unable to find any evidence whatever that bacteria attack rocks directly. The processes of nitrification and decomposition performed by bacteria are soil and surface phenomena in the main, and while these phenomena may penetrate to

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* Mémoire sur la composition de l'air confiné dans la terre vegetale. Boussingault et Léwy. Compt. Rend., 35, 1852, pp. 765–774.

† A Handbook of Systematic Botany. E. Warming. Translated by M. C. Potter. London, 1895, pp. 31, 32.

‡ Phil. Trans. Roy. Soc., 1890, B., p. 107; Nature, vol. xlvi, 1892, pp. 136–138.

§ Annales de l'Institut Pasteur, 1890, p. 268.

|| Exper. Station, Bul. 8, U. S. Dept. Agr., 1892, p. 42 et seq.

¶ Compt. Rend., 1893, cxvi, pp. 842–849.

** Compt. Rend., 1890, cx, p. 1370.

great depths, they can do so only when the way is prepared for them by the penetration of surface waters containing their essential food.

INORGANIC CHEMICAL AGENCIES.

The inorganic chemical agencies of decay which attack the rocks in Brazil are carbonic acid (in part) and nitric acid. Nitric and carbonic acids are both brought down by rain; the latter is also produced by organic decomposition and the former by nitrifying bacteria.

Carbonic acid (CO_2).—The carbonic acid attacking the rocks of Brazil is derived from two sources: from the air and from the decay of organic matter. The carbonic acid derived from the air is brought down by the rains. It was formerly believed that there was more of this gas in the air (from 4 to 6 parts by volume in 10,000) than later examinations have shown.* The determinations of Reiset, Van Nuys, Muntz and Aubin and others show conclusively that the amount is small and constant. Examinations in Paris and in the country by Muntz and Aubin showed—

> "That the variations of carbonic acid occur only between very narrow limits and under local influences, so that it may be said in general terms that carbonic acid is uniformly disseminated in the lower strata of the atmosphere." †

Further determinations by these authors, and described in the paper cited, show that at considerable elevations (2,877 meters on the Pic du Midi in the Pyrenees) the amount of carbonic acid scarcely differs from that in the air near the sea-level.

Another noteworthy fact is that determinations made in the presence of abundant vegetation showed there was no marked difference. I lay some stress on this because in observing the character and amount of vegetation in Brazil I presumed that the decay of so much organic matter must necessarily return large quantities of carbonic acid and ammonia to the air. However much of these substances decaying vegetation may yield, it may be considered as demonstrated that they do not pass into the air, but are carried into the ground by meteoric waters.

The determinations of the above cited authorities show that the amount of carbonic acid in the air varies only between 2.76 and 3 volumes in 10,000,‡ and this must be regarded as a practical demonstration that the air is not washed clear of carbonic acid by rains, as was formerly supposed. The carbonic acid in the atmosphere has been determined at Para. § For reasons given above, however, these results are not regarded

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* Estimations of carbonic acid in the air. T. C. Van Nuys and B. F. Adams. Amer. Chem. Jour., vol. ix, no. 1.

† Sur les proportions d'acide carbonique dans les hautes regions de l'atmosphere. A. Muntz et E. Aubin. Comptes Rendus, 93, 1881, p. 797.

‡ Sur l'acide carbonique normal de l'air atmosphérique. M. Dumas. Comptes Rendus de l'Academie des Sciences, 94, 1882, pp. 589–594.

§ Thorpe in Jahresbericht der Chemie, 1867, p. 183.

as trustworthy, and in their place we are obliged to use those made by the Transit of Venus Commission of the French Academy in 1882 and 1883 at Saint Augustine, Florida; in Haiti, in Martinique, Puebla, Fort Loreto, Mexico, and at Cerro Negro, in Chile. These determinations, while they average a little lower than do those made in Europe, vary only between 2.665 in Chile and 2.897 volumes in 10,000 in Florida. It seems probable, therefore, that while there may be less carbonic acid in the air in the tropics the difference is scarcely perceptible.[*]

Fischer[†] gives several determinations of carbonic acid in rain and snow-water which show that the amount varies much in spite of the constant amount in the air. The carbonic acid in rainwater is between 6.7 and 14.1 per cent by volume of all gases found in the water, which is equivalent in the cases cited to from 0.22 to 0.45 per cent by volume of water.

The actual amount of carbonic acid carried down in the rains is determined from these figures and from the rainfall.

The rainfall at various places in Brazil is given in the table below, and if we assume that the amount of carbonic acid brought down by the rain in Brazil is a mean between the extremes given in the table, or 0.33[‡] of one per cent by volume (equivalent to .0065 grains in 1,000 by weight) we should have precipitated in the rains the amounts of carbonic acid given in the fourth column.

Mean annual Rainfall in Brazil.[§]

Station.	Years of observation.	Rainfall in millimeters.	Millimeters of CO_2 in rainfall.
Rio de Janeiro	29	974.6	3.21
Santos, S. Paulo	15	2,503.0	8.26
Serra do Cubatão, S. Paulo	15	3,576.7	11.80
São Paulo	4	1,494.1	4.93
Uberaba	3	1,560.8	5.15
Morro Velho, Minas	25	1,637.0	5.40
Gongo Soco, Minas	2	2,939.3	9.70
Pará	4	1,788.7	5.90
Ceará	28	1,491.5	4.92
Pernambuco	8	2,971.7	9.80
Victoria	7	1,050.5	3.46
Colonia Isabel	6½	1,037.0	3.42
S. Bento das Lages	5	2,179.5	7.19
Bahia	5	2,394.8	7.90

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[*] Determinations de l'acide carbonique de l'air dans les stations d'observation du passage de Venus. A. Muntz et E. Aubin. Comptes Rendus, 96, 1883, pp. 1793–1799.

Die Chemische Technologie des Wassers. Ferdinand Fischer. Brauschweig, 1880, pp. 75, 76.

[‡] This amount is two-thirds greater than the theoretic amounts given by Roth (Allgemeine und Chemische Geologie. Berlin, 1879, i, p. 44), but inasmuch as they are taken from actual determination it seems best to adhere to Fischer's figures.

[§] Die Vertheilung der Regenmengen in Brasilien. Von Professor F. M. Draenert. Meteorologische Zeitschrift, Sept., 1886, pp. 381–319.

Important as is the carbonic acid brought down in rains in Brazil, the great quantity produced on the ground, especially in the forest-covered portions, is vastly more so. It comes from the decay of organisms upon the surface and in the ground and from the breathing of subterranean animals. This has been considered under the head of "Organic chemical agencies."

Nitric acid (HNO_3).—Little account has been taken of the amount and influence of the nitric acid brought to the earth in rains and of the part it performs in the decomposition of rocks in the tropics.[*] Nitric acid is produced in the air by electric discharges, and such discharges are much more violent and more frequent in the tropics than in temperate regions, and it may reasonably be expected therefore that the amount of nitric acid thus produced is proportionately larger.[†] That such is the case has also been determined by actual examinations of rain-waters in temperate and tropical regions. It is true that the composition of the granites and gneisses is such that these rocks are not attacked directly by nitric acid, but, as is well known, time and the complex processes of weathering eventually bring them within the range of influences by which they are at first but little affected. Falling upon a soil covered with organic matter, there can be no doubt but that this nitric acid is quickly reduced to ammonia; but, as has been suggested by Julien, it would tend even in this case to form organic acids of higher oxidation.[‡]

Muntz and Marcano have determined from two years' observations, embracing 121 rainfalls in 1883–'84-'85, the amount of nitric acid contained in the rain-water at Caracas, Venezuela.[§] These are the only determinations made in the tropical part of South America of which I have any knowledge. The climatic conditions at Caracas, Venezuela, seem to make the observations at that point readily available for Brazil, for Muntz and Marcano remark that "the climate is characterized by a temperature that varies but little, by the unequal distribution of the rains and by the violence and frequency of storms." The determinations from 19 rainfalls at Saint Denis, Bourbon island, are especially interesting, as

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[*] So far as I know, the first suggestion of the influence of nitric acid in rock decomposition in the tropics was made by Heusser and Claraz in their article upon the Gisement et exploitation du diamant dans la province Minas Geraes au Brésil. Annales des Mines, 5me sér., xvii, 1860, p. 291; also Zeitschrift der Deutchen Geol. Gesell., xi, p. 448.

[†] Muntz and Aubin say that carbonic acid is also produced by electric discharges (Comptes Rendus, 99, 1884, pp. 871–874), but the amount of carbonic acid brought down by rain was accepted from the determinations regardless of the method of its formation. It is possible, however, that the electric discharges make a perceptible difference in the carbonic acid, and that the amount thus produced in the tropics will necessarily be greater than in temperate regions.

[‡] Proceedings Amer. Assoc. Adv. Sci., 1879, p. 327. Ammonia salts also hasten mineral solution. Johnson's How Crops Feed, pp. 139–140.

[§] Comptes Rendus, 108, 1889, pp. 1062–1064.

that place is about the same latitude as Rio de Janeiro. These determinations seem to show that much more nitric acid falls in the tropics than in temperate regions. This may readily be seen by making a comparison of the following statements of determinations made in several localities:

Determinations of Nitric Acid (HNO_3) in Rainfall.

Station.	Nitric acid (milligrams per liter of rain-water).	Authorities.
Caracas, Venezuela	2.23 (mean)	Muntz and Marcano (1).
Saint Denis, Bourbon island	2.67 (mean)	Muntz and Marcano (1′).
Sourabois, Java	2.3–2.87	Homans (1″).
Lincoln, New Zealand	0.578	G. Gray (2).
Tokio, Japan	0.327	Kellner (2).
Pic du Midi, Pyrenees	trace only	Muntz and Aubin (3).
Rothamsted, England	.670, mean for 1 year	R. Warington (4).
Manhattan, Kansas	.702, mean for 3 years	Failyer, Willard and Breese (5).
Liebfrauenberg, Alsace	.180	Boussingault (6).

The determinations of nitric acid in rain-water, both in temperate and tropical regions, show that the amount is not constant, and the figures given in the above table must be looked upon as means that fluctuate greatly. At Caracas, for example, a maximum of 16.25 was reached on one occasion and on another a minimum of 0.20 milligrams to the liter. The amount doubtless varies with the electrical discharges, as Muntz and Marcano state.*

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(1) Comptes Rendus, 108, pp. 1062–1064; elevation of Caracas station, 922 meters.

(1′) Comptes Rendus, 108, p. 1062; 19 observations; maximum, 12.5; minimum, 0.4.

(1″) Annales Agronomiques, Paris, x, 1884, pp. 83, 84.

(2) Quoted from Warington. Jour. Chem. Soc., vol. lv, 1889, p. 543.

(3) Sur la nitrification atmospherique. Muntz et Aubin. Comptes Rendus, 95, 1882, pp. 919–921. In 6 rains, 3 fogs, and 4 snows they found "almost a complete absence of nitrates."

(4) The Amount of Nitric Acid in the Rainwater at Rothamsted. R. Warington. Jour. Chem. Soc., vol. lv, 1889; Transactions, pp. 537–542. Warington's mean for the year is given as 0.139, but his figures add up 0.149. I have used the latter. I have regarded the nitrogen as nitrates, for, as Warington says, the amount of nitrous acid is "extremely small and only to be appreciated by the delicate napthylamine test."

For other determinations see Annales Agronomiques, 1881, vii, pp. 429-456; also On the amount and composition of the rain and drainage waters collected at Rothamsted. Lawes, Gilbert and Warington. Jour. Roy. Agr. Soc. of England, 2d ser., vol. xvii, 1881, pp. 241–279; pp. 311–350. On page 268 the nitrogen is given for 9 other stations. See also Recherches sur l'existence et le role de l'acide nitreux dans le sol arable. Ch. Chabrier. Annales de Chimie et de Physique, 4me sér., 1871, xxiii, pp. 161–193.

(5) Ammonia and nitric acid in atmospheric waters. Second Annual Report Experiment Station Kansas Agricultural College for 1889. Topeka, 1890, pp. 123–132; Trans. Kansas Acad. Sci., vol. xii, 1889–'90, pp. 21–24.

(6) Quoted from Muntz and Marcano. Comptes Rendus, 108, p. 1063.

*Comptes Rendus, 108, p. 1062.

Accepting the means here given as being as near the truth as we can get with the available data, the amount of nitric acid brought down by rains in Brazil can be determined approximately from the rainfall.

Taking the precipitation tabulated below and accepting the determination of nitric acid for Caracas as the one most likely to be the correct one for Brazil, we should have for the year the amounts given in the second column of the table.

Total Nitric Acid (HNO_3) free and in Ammonia in mean Rainfall in Brazil.

Station.	Rainfall (in millimeters).	Nitric acid (HNO_3) (in millimeters).	Nitric acid (HNO_3) from ammonia in rain water (in millimeters).	Total nitric acid (HNO_3) (in millimeters).
Rio de Janeiro	974.6	.00142	.00444	.00586
Santos, S. Paulo	2,503.0	.00365	.01141	.01506
Alto da Serra	3,576.7	.00521	.01630	.02151
São Paulo	1,494.1	.00218	.00681	.00899
Alto Parnahyba	965.6	.00141	.00440	.00580
Uberába	1,560.8	.00227	.00711	.00938
Morro, Velho	1,637.0	.00238	.00746	.00984
Gongo Soco	2,939.3	.00428	.01339	.01767
Itabira	1,303.5	.00189	.00594	.00783
Queluz	1,453.1	.00212	.00662	.00874
Manáus, Amazonas	2,340.4	.00341	.01067	.01408
Pará	1,788.7	.00261	.00815	.01076
Ceará	1,491.5	.00217	.00679	.00896
Pernambuco	2,971.7	.00433	.01354	.01787
Victoria	1,050.5	.00153	.00478	.00631
Colonia Isabel	1,037.0	.00151	.00472	.00623
S. Bento das Lages	2,179.5	.00318	.00993	.01311
Bahia	2,394.8	.00349	.01091	.01440

Determinations have been made at several places in the world of the amount of ammonia brought to the earth in rain water. This ammonia must also be counted among the indirect agencies of rock decomposition, though it is perhaps no more important in Brazil than elsewhere, except in so far as the amount is greater, as shown by Muntz and Marcano, and as the warm climate may increase its activity. Warington has shown that all nitrogenous substances which yield ammonia are nitrifiable.* Ammonia in contact with organic matter is soon converted into nitric and nitrous acids. In water analyses, for instance, it is understood that waters which give ammonia when fresh, yield only nitric and nitrous

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* Jour. Chem. Soc., London, vol. xlv, p. 653.

acids after standing for some time. Nitrification takes place principally if not exclusively in the surface soil.*

In order to estimate the nitric acid in the ammonia falling in rain in Brazil we are compelled to get our ideas of the amount in the rain-water from the determinations of Muntz and Marcano at Caracas, Venezuela. The total ammonia falling in the rain at that place on being oxidized to nitric acid amounts to 6.975 milligrams of nitric acid to the liter of rain-water.†

Thus the table on page 308 gives the total depth of nitric acid falling in the rains in Brazil, both in the form of ammonia and as nitric acid.

RAINFALL.

It is evident that the rainfall must be an important factor in all this rock decomposition; both the amount and the time distribution are important elements. At one of the stations from which we have a record—that of the Alto da Serra do Cubatão, where the Santos à Jundiahy railway crosses the Serra between Santos and São Paulo—an average for 15 years gives a rainfall of 3,576.7 millimeters (140.81 inches, or more than 11 feet), and from this extreme it declines to about 50 inches. Moreover, the rainfall is very unevenly distributed throughout the year, most of the precipitation occurring in three or four months. This same precipitation, large as it is, if more evenly distributed throughout the year would do only a fraction of the eroding that it does when thus poured in torrents upon the earth.‡

The year is roughly divided by the people into the two seasons which are known as the sunny weather (*tempo de sol*) and rainy weather (*tempo de chuva*). The tempo de sol is the time of cool weather in that country—usually the months of May, June, July, August and September—the sol referring not to the heat, but to the continuity of the sunshine. The rainy season is the hot part of the year, and this is a point to be borne in mind, for the rains alternating with hot sunshine, the waters fall upon hot rocks or soils and their chemical activity is greatly increased by this increase of temperature.

The concentration of the rainfall in a few months of the year is a constant feature of the Brazilian climate, although it often varies considerably from one year to another—that is to say, November may be a very rainy month one year and comparatively little rain may fall the follow-

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* Warington: Jour. Chem. Soc., vol. li, p. 118.

† Comptes Rendus, 1891, cxiii, p. 780.

‡ Lake Bonneville. G. K. Gilbert. Monograph I, U. S. Geol. Survey, pp. 41, 42. This principle is employed in the process of gold washing known as "booming."

ing November, and this may be true not only of one but of several of the months.

Traveling in the interior of the country at certain seasons of the year, one is impressed by the dry beds of what are, at other times, large rivers. This is especially striking in the northeastern part of Brazil, through the interior of Bahia, Pernambuco, Parahyba, Rio Grande do Norte, Ceará, and Piauhy. Streams that are at one season large enough to float an ocean steamer and from a hundred to two or three hundred miles in length, often, toward the end of the dry season, are reduced to a series of pools or to a line of hot white sand. This fact is so well known that it is scarcely necessary to do more than mention it here, and the statement is not intended to apply to years of drouth, but to the average condition of the region in question.

In Bahia, in the month of May, Spix and Martius found the Rio do Peixe and the Rio Itapicurú, which is over 200 miles in length, only a string of pools.*

Barão Homem de Mello, who was better acquainted with the physical geography of Brazil than any one else, says, in speaking of the plains of Ceará:†

> "During this period (the dry season) the beds of streams, here improperly called rivers, dry up entirely. In this province, however, these are nothing more than channels or courses of torrential waters during the rainy season. Thus I crossed today the perfectly dry beds of the Bahú and Guayuba between Acarape and Pacatúba. Along the large streams, such as the Jaguaribe, which is more than 600 kilometers long, there are barely a few pools here and there, the water ceasing altogether to flow." This is borne out by Gardner, who says that at Icó the Jaguaribe, "which during the rains is of considerable size, becomes quite dry" in the dry season.‡

In the Rio Grande do Norte Koster found the Ceará Merim in November a dry bed its entire length above tidewater. The Rio das Paranhas, the largest stream in that state and in Parahyba do Norte (250 miles long) he found dry at Açú, near its mouth, on December 1, but on recrossing it two weeks later he found it overflowing its banks and "two to three hundred yards in breadth."§

Even under the equator the rainfall is thus unequally distributed. There are dry treeless plains at many places along the Amazon. Hartt,

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* Reise in Brasilien, ii, p. 724.

† Excursões pelo Ceará. F. I. M. Homem de Mello. Revist. do Inst. Hist. do Brazil, 1872, xxxv, pt. 2, p. 85.

‡ Edin. New Phil. Jour., April, 1841, p. 76.

§ Travels in Brazil. Henry Koster. 2d ed., London, 1817, vol. i, pp. 113, 147, 217.

speaking of the dryness of the climate of the Amazon valley, says that the forests of the Monte Alegre, Eréré district, and of Santarem bespeak "during the dry season a very dry climate and a fault of moisture."[*]

My own observations show that the plains north and northeast of Macapá are so dry and parched during a large part of the year that trees grow only along the streams or in other favored places.

The rains, even during the rainy season, have a decided torrential character. Pompeo de Souza mentions a rain at Ceará in 1855 when a rain gage, 200 millimeters deep, overflowed.[†]

Using Dr Draenert's table of mean rainfalls, compiled from all the data obtainable at the time of its publication, in 1886, we find that the precipitation was distributed as shown in the following table:

Distribution of Rainfall by Semesters.[‡]

No. of years.	Station.	Rainfall (in millimeters).	Six rainy months (in millimeters).	Six dry months (in millimeters).
29	Rio de Janeiro	974.6	632.9	341.7
15	Santos, S. Paulo	2,503.0	1,708.9	794.1
15	Alto da Serra, S. Paulo	3,576.7	2,289.5	1,267.2
4	São Paulo	1,494.1	1,152.6	341.5
1	Alto Parnahyba	965.6	748.0	217.6
3	Uberaba	1,560.8	1,292.5	268.3
25	Morro Velho, Minas	1,637.0	1,457.0	180.0
2	Gongo Soco, Minas	2,939.3	2,510.1	429.2
1	Itabira, Minas	1,303.5	1,120.8	182.7
1⅔	Queluz, Minas	1,453.1	1,251.4	201.7
4	Manáos, Amazonas[§]	2,340.4	1,675.9	664.5
4	Pará	1,788.7	1,426.3	362.4
28	Ceará	1,491.5	1,347.4	144.1
8	Pernambuco	2,971.7	2,453.0	518.7
7	Victoria, Espirito Santo	1,050.5	779.4	251.1
6½	Colonia Isabel	1,037.0	839.8	197.2
5	S. Bento das Lages, Bahia	2,179.5	1,562.4	617.1
5	Bahia	2,394.8	1,795.2	599.6

By taking shorter periods—say three months – this contrast comes out still more strongly.

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[*] Bul. Buffalo Soc. Nat. Hist., 1874, p. 227.

[†] Ensaio Estatistico da Provincia do Ceará. Thomaz Pompeo de Souza Brazil. i, 1863, p. 116.

[‡] The totals are taken from Dr Draenert's Vertheilung der Regenmengen in Brasilien. Meteorologische Zeitschrift, Sept., 1886. They cover a longer and fuller series of observations than that given by Professor Loomis. Amer. Jour. Sci., vol. xxv, 1883, p. 3.

[§] Revista do Observatorio do Rio de Janeiro, vol. vi, 1891, p. 169.

Maximum and Minimum Rainfall by Trimesters.

Stations.	Maximum rainfall for three months (in millimeters).	Minimum rainfall for three months (in millimeters).
Rio de Janeiro	349.3	135.9
Santos	1,006.2	360.7
Alto da Serra	1,308.6	587.5
São Paulo	810.7	111.9
Alto Parnahyba*	563.2	0.0
Uberaba	840.9	68.0
Morro Velho	923.0	39.0
Gongo Soco	1,715.5	109.4
Itabira*	732.9	0.0
Queluz	943.9	53.8
Manáus, Amazonas	955.4	176.8
Pará	871.6	128.7
Ceará	941.8	41.4
Pernambuco	1,682.5	106.7
Victoria	469.2	61.6
Colonia Isabel	492.4	64.6
S. Bento das Lages	981.5	235.4
Bahia	1,156.3	256.7

The little rain that falls during the dry months is not enough to fill the streams, but it all or nearly all soaks into the dry ground at a time when it is highly effective as a chemical agent. The effect of long dry periods upon the soil should not be overlooked. In many places, especially in the clayey lands and in the soils derived from the calcareous rocks of the Cretaceous belt, great cracks open the soil to a depth of from 5 to 10 feet, according to the length of the dry season. These crevices admit atmospheric air and gases readily to a considerable depth, organic matter is constantly falling into them, and when rains come the surface waters penetrate at once to their bottoms and fill the whole upper soil.

It is worthy of note that so far as our defective statistics go they show that the rainfall is largest along the east coast of Brazil, where the southeast air currents from the Atlantic first strike the continent. This region also includes the principal gneiss and granite area of Brazil and the region of decomposed schists and shales of the Minas water-shed.

Rate of Decomposition.

No data are at hand for an exact determination of the rate of rock decomposition in Brazil. Some of the oldest gneiss buildings do not exhibit any marked evidences of decay, while others are clearly soft-

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* Observations for one year only.

ened by the decay of the feldspar. It is doubtful, however, whether these cases of the decay of building stones can be taken in evidence. The walls and buildings first constructed of gneiss in Brazil were in all probability made of rock from the surface or from near the surface, and possibly already more or less affected.

The most marked evidences of decay are along the joints between separate blocks in some of the old buildings. Here there is often a rounding off of the corners and a crumbling of the mortar. Doorposts and pillars of stone are sometimes affected at the bottom and not at the top, due, no doubt, to the greater amount of organic acids and moisture reaching these lower points. Such cases, however, are not to be taken into consideration in the discussion of rocks under natural conditions. It is certainly true that the agents of rock decay are much more active in Brazil than in cooler climates. Caldcleugh expressed the opinion years ago that in Europe "the agents of destruction are feeble compared with those of a tropical country."*

It is also to be noted that waters falling upon and flowing over these bare rocks are, to begin with, unsaturated and therefore have greater dissolving power than spring or stream water.

RÉSUMÉ.

1. Decomposition is widespread and deep; depths of 100 feet are common; some of more than 300 feet are known.
2. Land-slides caused by deep decay are abundant.
3. Decomposition is not universal, and its absence is especially to be noted in the Cretaceous and Tertiary areas.
4. Talus slopes are rare.
5. Mountains and peaks of gneiss and granite exfoliate like enormous boulders of decomposition, producing a characteristic topography which often resembles glaciated surfaces and *roches mountonées.*
6. The fragments of nearly all the massive homogeneous rocks tend to exfoliate.
7. Openly exposed blocks of massive crystalline rocks sometimes weather in trenches or in fluted boulders.
8. Changes of temperature cause the openly exposed rocks to crack and to exfoliate. But little decomposition is caused by the direct action of changes of temperature in Brazil, but they open crevices in the rocks which admit moisture and acids—the principal agencies of rock decay.
9. The daily range of temperature sometimes amounts to more than 100 degrees Fahrenheit.

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* On the geology of Rio de Janeiro. Alexander Caldcleugh. Trans. Geol. Soc., 2d ser., vol. ii, 1829, p. 69.

10. An important factor in the decomposition of the rocks is the fact that the rainy season is the hot season, and the waters falling upon hot rocks have their temperatures raised to about 140 degrees.

11. The dark color of the rocks increases their absorbing and radiating power and consequently the range of temperatures to which they are subject.

12. The unequal expansion and contraction of minerals with changing temperatures hasten the disintegration of rock surfaces.

13. The mechanical effects of changes of temperature, however, are surface phenomena.

14. The coarse textured rocks seem to be more susceptible to decomposing agencies than the more compact ones.

15. Insects living in the ground, especially the ants and termites, contribute large quantities of organic acids to rock decomposition.

16. Plant life is especially rank, and both growth and decay are more rapid than they are in temperate regions. Plants are the chief source of the acids which attack the rocks of Brazil.

17. Carbonic acid is also brought to the earth in large quantities by the rains.

18. Nitric acid is produced and brought down by the rains in much larger quantities than in temperate regions.

19. The rainfall of Brazil is very large, ranging from 974.6 millimeters at Rio de Janeiro to 3,576 millimeters on the Serra do Mar, in the state of São Paulo.

20. The concentration of the rainfall renders it more effective both chemically and mechanically.

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RELATIONS OF GEOLOGIC SCIENCE TO EDUCATION

ANNUAL ADDRESS BY THE PRESIDENT, N. S. SHALER

(*Read before the Society December 27, 1895*)

CONTENTS

INTRODUCTION

The custom has been established which requires the retiring President of this Society, as other societies which have for their purpose the advancement of science, to set forth his views concerning matters related to the interests which the association seeks to promote. This custom evidently rests on the reasonable presumption that the officer during his term of service has been led by his duties to consider how the cause which he represents may be promoted, how its store of truth may be enlarged, and in what manner it may best be made to serve the interests of mankind. This task may be essayed either by a survey of the work which has recently been accomplished in the science, with appropriate comment on the trends and results of the endeavors, or the essayist may restrict his undertaking to some one portion of the field with which he is conversant in the hope that he may be able to present the fruits of his own labors in a way which is likely to be profitable to others. For various reasons I have chosen the latter of these alternatives and have taken for my subject the relations of geological science to education.

Under this title I shall not only include those questions which pertain to pedagogy, but certain larger aspects of the matter which relate to the needs of society, both from the moral and the economic point of view.

Relationship of Teaching and Research defined.

I have been in good part led to take up this subject for the reasons that the title itself is a protest against the modern notion that the work of research should be separated from that of teaching; that natural inquiry should be released from the ancient and profitable connection with education which in my opinion has advanced and ennobled both these branches of learning. Those who seek to have inquiry endowed are led to the endeavor by a true sense of the importance of the tasks with which the path-seekers in the fields of nature have to deal. They are, moreover, guided to their object by the motive which leads to the division of labor in all work which men do, whether in economics or in pure learning. Undoubtedly a certain kind of success would attend the complete separation of the students of phenomena from those whose business it is to impart knowledge; but there are gains which, though immediate, are not desirable, for the reason that they entail in the long run serious losses. It may well be apprehended that the definite separation of the inquirers in any science from those who are to teach the learning would result on the one hand in isolation of the men of the laboratory from the life of their time and on the other to a degradation of the instruction to a level where it would become mere formal tutoring, destitute of the penetrating spirit which gives value to scientific thought.

It seems to me that the explorer, if he be animated by the true spirit of his class, finds himself seeking for undiscovered realms, not for personal gains, nor, indeed, merely to add to the store of things known, but always with reference to the enlargement of mankind. His motive is in the highest sense that of the teacher; he limits his opportunities of personal culture if he denies himself the chance of communicating his gains to the youth of his time. It may be held that the investigator has his means of teaching through the press and the learned societies, but I need not tell my brethren of the craft that the opportunities of sympathetic contact with his fellow-men which are thus to be had are very limited; that they are quite insufficient to satisfy the natural desire of an ardent student of nature for relations with the life about him. The only way in which a really wholesome situation can be found for the naturalist in any of the realms of nature is to link his work with the tasks of education.

Viewed from the point of view of the student of science, who has to catch the spirit of inquiry from the word of the master if he is to win it at all, we see that the teaching function of the inquirer is of the utmost importance to his science. We all recognize and deplore the evils which arise from the fact that young people have to be introduced to most branches of learning by teachers who have little chance to gain or to preserve the spirit of inquiry. We can at most hope that the scientific motive may come to these instructors through a study of the psychology which properly underlies their work. It is unreasonable to suppose that they will be able to bring to their work the stimulating influence of those who are a part of the learning they convey. Therefore if men are to be bred in the ways of the naturalist, the task must be done by investigators. It goes, or should go, without saying that while these men may give and receive profit from their positions as teachers, they should not be called on to do the share of this work which is often inflicted on them, as it is on the teaching body of our schools in general. A condition of this combination of inquiry and instruction is that the two should be associated so as to give the men of science leisure for their studies as well as an opportunity to influence youths by their teachings.

Interdependence between Research and Instruction in Geology.

There are good reasons why the connection between research and instruction should be preserved in geology, even if it be abandoned in the case of the other sciences. In those other branches of natural learning the subject-matter can be brought into the laboratory, or at least, as in the case of astronomy, be in some measure made immediately visible to the student, but in geology only a very small part of the fact can be demonstrated by laboratory means. Even where the teacher finds himself in a field which is rich in illustrations, he is sure to lack examples of the greater part of the important facts which he has to bring to the understanding of his pupils. Under these conditions good teaching depends upon the development of the inquiring spirit without the stimulus of a satisfactory direct contact with phenomena. This task cannot be accomplished by any routine methods or by instructors who are not true men of science. It can only be done by those who have the spirit of the investigator in them, who know the range of fact in the intimate and personal way which will enable them to arouse the constructive imaginations of the youth to the task of picturing the unseen—a task which is at the foundation of the best culture which science has to give.

A capital instance of what can be done by a teacher who is also an inquirer is afforded by the work of Louis Agassiz in extending the interest in glacial geology in this country. His lectures on the subject were so vivid, they so effectively presented the physiognomy of the Swiss glaciers, that they quickened the imaginations of the dullest persons. They aroused an interest in the matter which was so intense and on the whole so well informed that the study of glacial geology in the larger sense of the term developed more rapidly and on better lines in this country, where existing ice fields are lacking, than in European lands, where examples abound. In such work we see the part of the master in instruction. As a contrast I may be allowed to relate a story which gives us a notion of what science teaching is likely to become when it is left to the people of routine.

The professor of mineralogy in Harvard University one day observed two young women examining his mineral cabinet, one of whom was evidently searching for some particular species. Offering his help, he found that the object of her quest was feldspar. When shown the mineral she seemed very much interested in the specimens, expressing herself as gratified at having the chance to see and touch them. The professor asked her why she so desired to see the particular mineral. The answer was that for some years she had been obliged to teach in a neighboring high school, among other things, mineralogy and geology, and that the word feldspar occurred so often in the text-book that her curiosity had become aroused as to its appearance.

It will, of course, be possible to give the routine teachers some practical knowledge of feldspar and of the other matters of fact with which they have to deal in their text-book work, but the motive, or the lack of it, which is indicated by the incident will always have to be reckoned on as inseparable from the mill-work of ordinary schools. So far as geology is concerned, the instruction of this text-book kind which may be essayed in the secondary schools is quite in vain; its only effect is to make the youths on whom it is inflicted quite unapproachable by the teacher who may afterwards undertake to introduce them to geology. All of us who have taught in colleges know the youth who has had somebody's "six weeks of geology" rubbed in by a drudge who, if required to do so, would in a like way have applied Sanscrit. We know that the youth who has been so misused is in most cases, provided he is not blessed with a good capacity for escaping the influences of education, utterly unfit for our uses. The most *economical* thing to do, in the large sense of the word, is to give him the advice which the elder Agassiz was wont to give to those of his students who proved impregnable to his methods of instruction: "Sir, you better go into business."

Value of geological Education and Methods of Transmission.

COMPREHENSIVE CHARACTER OF GEOLOGY.

Assuming, as we needs must, that as geologists it is our duty not only to extend the learning of the science, but also to take charge of its diffusion among the people, let us consider in general the value of good which we have to deliver and the manner in which the transmission may best be effected. So far, doubtless for the reason that geologists are uncommonly busy people, there has been little note taken of the importance of the store of the science to society or the way in which the knowledge should be handed down. We have been content to harvest and have hardly considered the work of cultivation; therefore the assessment which I am about to give will doubtless need much revision.

In the first place, we should note well the fact that geology differs from all other divisions of natural learning in that it is not limited to a particular group of facts or modes of energy, but is in a way concerned with nearly all the work which is done in and on this sphere. We should, perhaps, except human affairs; but if he is so minded the geologist may make good his claim to a large share in interpreting that group of phenomena also. In fact, the earth lore is not a discrete science at all, but is that way of looking at the operations of energy in the physical, chemical and organic series which introduces the elements of space and time into the considerations and which furthermore endeavors to trace the combination of the various trends of action in the stages of development of the earth. It is in these peculiarities of geology that we find the basis of its value in education and in the general culture of society, which it is the aim of education to create. It should be in its province, as it is clearly in its power, to give to mankind perspectives which will serve vastly to enlarge the evident field of human action.

All observant teachers know that no true success in education is possible until we contrive an awakening of the youth from the sleepy acceptance of the world about him. To rid the student of this benumbing relic of the bone-cave, the spirit of the commonplace, there is no treatment so effective as that which it is in the power of the master in geology to give. The story of the ages clearly told, with a constant reference of the bearing of the matter on the appearance and the fate of man, will quicken any mind that is at all fitted to profit by the higher education. Although geology can hardly be said as yet to have made any such general impression on laymen as is justified by the body of truth which it has to deliver, the close observer may notice certain important changes in the state of the public mind which seem clearly to have been due to the teachings of the science. While many things go into the making of the world's judgments, there can be no question that the plain truths concerning the antiquity of the earth and the series of events which have led to the coming of mankind have in this generation been most effective in overturning sectarian bigotry and in other ways enlarging the spirit of all educated people.

It is evident that the main contribution which geology has to make to those conceptions which may enter into the spirit of our society relates to the position of man; the abstract learning, that which is in and for itself, is for those who have the professional interest. These public values of the science are of two diverse kinds—on the one hand those which pertain to intellectual enlargement; on the other, to economic development. Therefore in considering our duty by the educational side of our work we should see what the contributions can be to these two modes of endeavor and how they should be presented. First, I shall consider the limitations of that work which may be regarded as distinctly pedagogic.

DIVISIONS OF THE SCIENCE.

It seems to me necessary distinctly to separate the body of the instruction which is to be given in geology into two parts—that which is appropriate to the general public and that which, though "caviare to the general," fits the appetite of the professional-minded. We are indebted to the philosophical pedagogue Herbert for a statement of the self-evident proposition that interest in a matter must exist before information concerning it can be profitably communicated; therefore in our teaching we must take no end of care to provide this foundation for the attention. This care is particularly necessary in the matters of geology, for, as before remarked, the facts cannot often be exhibited in the experimental way as in the laboratories of chemistry and physics, where the touch of hand or the sight of controlled actions establishes a personal relation with the problems. The teacher of our science has to avail himself of certain antecedent motives which he can presume to exist in any normal youth which may provide the required foundation of interest. What I have to say on this point is the result of nearly a third of a century of experience in teaching geology, and is based on work which has been done with more than 4.000 students. The basis for the induction is sufficiently great to make the conclusions of value. These are in brief as follows: That instruction in geology, which is meant for those who have not acquired the professional motive, must find its basis of interest on either of two foundations—on the element of sympathy with all which relates to the fate of man which is native in all of us, or on the love of the open fields which every youth who is not utterly supercivilized has as a birthright. Each of those interests is in a way primal, both may be separately reckoned on as strong in nearly all youths who are fitted for the higher education.

CLASS-ROOM INSTRUCTION.

To make use of the motives which may interest the beginner in geology my experience has shown that the first thing to do is to give by means of familiar lectures a general acquaintance with those series of actions which show the long continuous operations of energy in the orderly march of events, taking pains at each convenient opportunity—there are many such—to note how these processes have served to bring about the conditions on which the development of peoples or of states depends. Thus, in treating of volcanoes, the very humanized story of Vesuvius or of Ætna, especially the dramatic episode of the death of Pliny the Elder, is worth much to the teachers for the reason that it serves to bring a sense of human affairs into a subject which for lack of illustration is apt to remain remote and therefore uninteresting. The fact that the story of these volcanoes, especially that of Vesuvius, is inwoven with that of men forms a bond between the mind of the novice and an order of nature which would otherwise be utterly unrelated to him. Again, in treating of seashore phenomena, the history of harbors and their relation to the development of states, affords a basis on which to rest the account of coastline work. Yet again, in the matters connected with the formation of mineral deposits, which from the nature of the subject are apt to be somewhat elusive, it is easy to fix the attention by reference to the relation of those stores to the needs of man. So, indeed, in all parts of this preliminary work of awakening and developing interest in his subject the teacher of geology, if he is to be successful, must go about his task on the supposition that he has to extend existing interests to his field. When men have for some hundred generations appreciated the earth as we would have them do it, the process of selection or the inheritance of acquired characteristics may give a birthright interest in the large problems of geology; but while here and there a youth may be found with a Hugh Miller's taste for the science, the teacher who reckons on having his class thus inspired will fail to achieve success.

METHODS OF FIELD TEACHING.

As soon as the teacher through his work in the lecture-room has succeeded in extending the natural inborn interests of his pupils to the problems of geology, instruction in the field should begin. In this part of the work there is need of a great change in the methods and aims of the teaching. While in the lecture-room the conditions require the didactic method and exclude that of investigation, the reverse is the case in the field. When I first essayed peripatetic teaching I made the grave mistake in endeavoring to lecture with the phenomenon as a text. In time I found that the fatigue and other disturbing conditions of the open made students unable to profit by any such didactic method, and that all such direct instruction should be done while they were in the more receptive conditions of the house. The true use of the field is to awaken in the pupils the habit of seeking for themselves. The teacher may trust in this task to the existence of an observant motive in men which is at its best when they are in the open air. All of us, however dull we may be in the housed state, have when afield a discerning humor which prompts us to learn the reasons for the unexplained occurrences of nature. This precious relic of the savage life, of the original motive of curiosity, which has been the source of man's advance on the most of his intellectual upgoings, is in average youths strong; it requires the deadening effects of a long and misspent life to eradicate it in any normal human being. It is to this element of curiosity, informed by the preliminary instruction of the lecture-room, that the teacher of field geology should mainly trust for his success.

In practice it will be found impossible completely to exclude didactic teaching in the field—such arbitrary divisions of methods are generally impracticable—but when in face of an exhibition of any geological phenomena, with the briefest possible preliminary, designed to fix the attention of the class upon the facts, the teacher should at once become a mere questioner, a goad to arouse the men to a like interrogation of the things they see. It is important that the first problems of interpretation which are essayed should be of the simplest order, for immediately successful work in the unaccustomed harness is much to be desired. Thus the determination of strikes and dips, the identification of visible faults, and above all, the careful recording of such facts, should come first and the work be carried to distinct success before any effort is made to use the results in the larger interpretations as to the attitudes of strata. In my experience it is most desirable in the early part of the field training to give all that can be obtained in the way of work which relates to causes of action, and thus, for the reason that men, however great their training may otherwise be, are unlikely to conceive the earth about them as a realm of continuous processes, their geology is thus not brought down to the present period. The beds and banks of the streams, the retreating escarpments, the shores of lakes and of the ocean—above all the, when rightly discerned, majestic phenomena of the soil—all may serve to impress the pupil with the activity of the earth, and thus clear his mind of the natural but blinding conception that after its creation time the sphere entered on an enduring rest.

DIFFICULTIES ENCOUNTERED IN FIELD TEACHING.

In my experience the difficulties which have to be met in field teaching, apart from the hard labor involved in the simultaneous exercise of mind and body, consists in the struggle which the instructor has to make with the incapacities which arise from the supercivilization of his pupils.

These hindrances are protean in form, but they are most commonly to be found in an inability to think in three dimensions any better than we can in four, and an incapacity to continue any work when alone. As to the first of these defects there seems to be no resource except to revive the natural dimensional sense which primitive peoples have. If the student has had sound training in solid geometry he may the more quickly recover the capacity to form the special conceptions which are required of the geologist; but the natural solid is quite another thing from the ideal, and while the theoretical view of them is the same the practical experience is very different. Some youths never learn to deal with the earth problems from the solid point of view. They are therefore cut off from the better uses of the field; yet even with this signal disadvantage they may do good work in certain parts of the science. One of the most distinguished of our American geologists, now dead, was, perhaps on account of the fact that he saw from but one eye, quite without the sense of the relations of the solid; yet, while in the field-work his success as measured by his talent was limited, his contributions in other departments were great and of enduring value. Nevertheless, though the people who abide in two dimensional spaces may possess abilities of a high order, they should be kept out of the science which more than any other calls for the ability to frame three dimensional conceptions.

An inability to work alone in the field is a rather common and in my experience an incurable defect in certain students who would otherwise be fitted for geology. Those who are thus afflicted appear to lose their motive of inquiry when they are parted from their fellow-men. Their malady is to be regarded as one of the many defects of body and mind which are due to over-housing—to that absolute separation from the peace of the wilderness which characterizes our city life.

As soon as possible the field student should be brought to the point where he is required to make his own maps, at first as sketches, and then in the more formal way by pacing, with some methodical control, such as by a simple triangulation. One piece of such map-work where the delineation of the surface in general ground plan and contour, as well as the geological coloring, is from his own labor will often be sufficient to affirm the working power of the man. In the ideal of the system such instruction should come to every student who undertakes the study of geology, but in practice it will probably be gained by very few. In the department of Harvard University which is devoted to the science about 300 men each year enter on the elementary work. Of these not more than the eighth part continues the study to the point where they may begin to do work which may be regarded as independent; yet fewer essay the training which looks forward to a professional career. As this department has been long established and is favorably conditioned to give instruction, the lack of a large attendance under a system of free election by students may be taken as an indication that while the elementary didactic presentation of the science attracts the greater number of the youths of our colleges, the higher branches are less attractive than the other similarly difficult work of the indoor learning. The conclusion is that geology in the larger sense of the term is, at least in the present condition of culture, an interest for a few chosen spirits who are so fortunate as to be born with a share of the world sense, or at least with an aptitude for studies which demands a measure of the primitive man which is not to be found in the most of our supercivilized folk.

UNDESIRABILITY OF TEACHING GEOLOGY TO IMMATURE STUDENTS.

In the demand which is now made for a beginning of all our sciences in the secondary schools it is proposed to include geology in the list and to set boys and girls of from fourteen to seventeen years of age at work upon the elementary work of the learning. For my own part, while it seems to me that some general notions concerning the history of the earth may very well be given to children, and this as information, it is futile to essay any study in this science which is intended to make avail of its larger educative influences with immature youths. The educative value of geology depends upon an ability to deal with the large conceptions of space, time and the series of developments of energy which can only be compassed by mature minds. Immature youths, even if they intend to win the utmost profit from geology, would be better occupied in studying the elementary tangible facts of those sciences such as chemistry, physics or biology, sciences which in their synthesis constitute geology, rather than in a vain endeavor to deal in an immediate way with a learning which in a good measure to be profitable has to be approached with a well developed mind. The very fact that any considerable geological problem is likely to involve in its discussion some knowledge of physics, chemistry, zoölogy and botany is sufficient reason for postponing the study until the pupil is nearly adult.

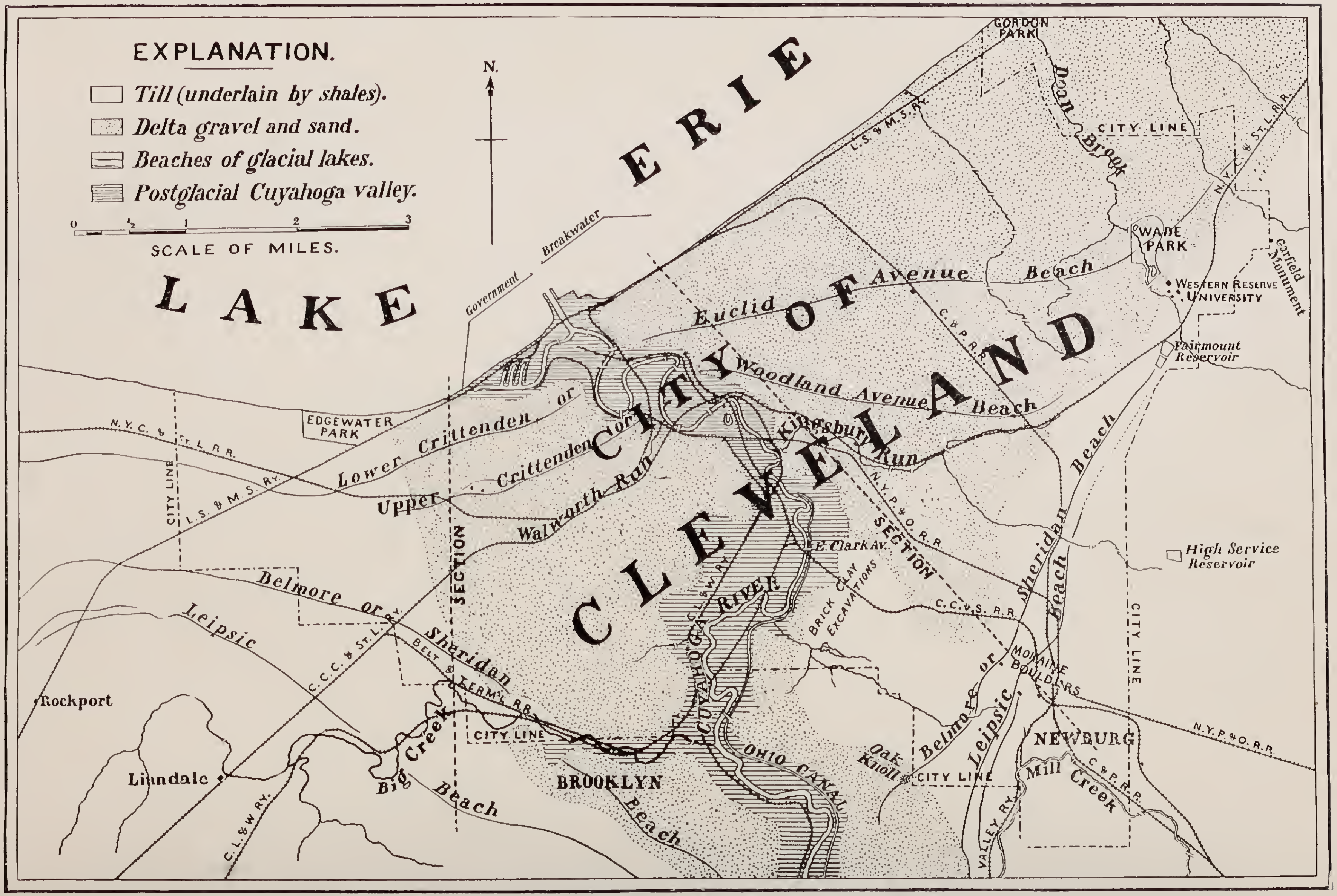
Expert Work and its Influence and Requirements.

Besides the relations to society which may be established by his position as a teacher, the geologist is from the character of his studies much called on for another kind of help, that which pertains to the development of earth resources or to the litigation which concerns earth values. In this field the relations are more critical and more perplexing than in that of instruction. The results of blundering are more apparent and their immediate effect on the reputation of the science more unhappy. That this branch of learning has managed to retain a fair place in the esteem of the public in face of the criminal blunders which its prophets have made is indeed remarkable. It shows how much our people are disposed to pardon where they believe that men mean well, however ill may they do. There is, however, a lesson from this unhappy experience which we should all read and inwardly digest. This is in effect that what is called expert work demands other qualities of mind and another training than those which go to make a successful investigator or teacher. We, as well as the general public, need to recognize that fact, that there is as much reason to suppose that a noted teacher of political economy should prove successful in determining the merits of a proposed business project as that his colleague in geology should be fit to advise in regard to a mining venture. The teacher may be an expert in the economics of the profession, but the proof of the fact is not to be found in his scientific work or in his success as an instructor. If he has not had the other training, it may be safely assumed that he will be totally unfitted to wrestle with the tricky fellows who try in amazingly varied ways to deceive him, or even with the tendencies of his own mind, which naturally lead him to see riches where others fancy they discern them.

In the interests of our science it is most desirable that all expert work should pass into the hands of a body of men who should bring to their task so much of geology as is needed for the particular inquiry, commonly not very much, and who can join with it the more important practical acquaintance with the miner's art and the conditions of trade which relate thereto. In certain cases the men of theory may well serve these experts; all their inquiries are likely to be of service in the determinations, but on them should not be the responsibility for the business side of the problems. There is little the geologist does in the way of research which may not have some practical application to the affairs of men, but he should not mistake this possibility of usefulness as an indication that it is for him to give his inquiries an economic turn.

CONCLUSION.

We thus see that geological science, like the most of the other branches of natural learning, has two distinct points of contact with society—that of instruction and that of economic affairs. In each of these fields of usefulness its services to man have been great and are to be far greater in the time to come. As for instruction, the task is to give to men an adequate perspective for their lives. It is to ennoble our existence by showing how it rests upon the order of the ages. In the economic field it is to show the resources which these ages have accumulated in the earth for the service of the enlarged man, who is to attain his possibilities by a full understanding of his place in nature. To do the fit work we need to combine the functions of explorers and guides zealous to open the way to the unknown, and those of teachers who take care that the youth of our time are led into the land which we know to have so much promise for man.



THE CUYAHOGA DELTA AND GLACIAL LAKE BEACHES IN CLEVELAND, OHIO

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PREGLACIAL AND POSTGLACIAL VALLEYS OF THE CUYAHOGA AND ROCKY RIVERS

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(*Read before the Society by title December 28, 1895*)

CONTENTS

THE CUYAHOGA VALLEY.

EXTENT OF THE DRAINAGE BASIN.

The highest springs of the Cuyahoga drainage basin are in northeastern Geauga county, in northeastern Ohio, about fifteen miles south of the shore of lake Erie. Thence the Cuyahoga river flows first about forty miles southwestward to its great bend close north of Akron, there turning to a general course slightly west of north which it holds through its lower thirty miles, entering lake Erie after passing through the central part of the city of Cleveland. This paper considers chiefly the last four miles of the Cuyahoga valley which are comprised within the limits of Cleveland. The level of the river in its stage of low water along this distance, from the junction of Big creek to its mouth, is the same as lake Erie, or differs only by a descent of 1 or 2 feet. Along all the south-to-north part of the river it flows now in its preglacial valley, which has much drift beneath the stream.

PREGLACIAL WIDTH AND DEPTH.

Where the Cuyahoga river enters the county of this name, at a distance of about thirteen miles from its mouth, the rock bottom of the preglacial valley is known by wells bored for oil, according to Professor J. S. Newberry in the reports of the Geological Survey of Ohio, to be 220 feet below the present river, or approximately 175 feet below the level of lake Erie. Again, at the junction of Kingsbury run in Cleveland, two and a quarter miles from the mouth of the river, a well bored by the Standard Oil Company penetrated 238 feet of drift, to the depth of 228 feet below the river and lake, and 18 feet below the bottom of the lake at its deepest place, before entering the bed-rock. During preglacial times the Cuyahoga here eroded a valley twice as deep as that which it now has, with a width nearly the same as now—that is, about one mile, excepting within the five miles next to the present lake Erie, where the old valley expanded gradually to be about seven miles broad before its bluffs were merged with the general escarpment south of the great lowland which now is covered by the lake.

PARTIAL FILLING WITH GLACIAL DRIFT.

The section of the drift 238 feet deep in the well at the mouth of Kingsbury run consisted mainly of till (called "blue clay" by Newberry), with occasional layers or seams of sand and gravel, ranging from 1 to 5 feet in thickness. The till here also reaches in the bluffs about 50 feet above the top of the well, giving nearly 290 feet as the whole depth of the glacial drift deposited in this broad part of the valley near its opening out to the plain of the lake basin. At the shore end of the water-works tunnel, a mile west of the present mouth of the river, the depth of drift to the bed-rock was found to be 78 feet below the lake level; at the engine-house of the water works, about a half mile nearer the center of the valley, the drift reached 100 feet below that level; and at the crib, one and a quarter miles offshore, the bottom of the drift was found at the depth of 116 feet, the water of the lake there being 24 feet deep. Throughout the whole tunnel, 65 feet below the lake surface, from the shaft at the shore to the crib, the drift was a compact and very clayey bluish till, containing small rock fragments in abundance, mostly derived from the Erie and Huron shales of the region and of the great lake basin on the north, but holding only very rare boulders so large as one foot in diameter.

Till having nearly the same characters was also tunneled through during the summer of this year for laying a large water main beneath the river on Clark avenue, nearly a mile south of the Kingsbury run.

The axis of the preglacial valley, doubtless 250 feet deep or more at the lake shore, is a mile or more east of the present river's mouth, and the site of the water-works tunnel is on the somewhat gradually ascending slope of the rock westward from the preglacial river bed. Two-thirds of a mile farther west, in Edgewater park, the shale rises above the lake level, and thence forms the precipitous lake shore, 40 to 50 feet high, along the distance of six miles to the preglacial valley of the Rocky river.

In the east part of Edgewater park the wave-eroded shore cliff consists of till from base to top, about 40 feet above the lake. This till, like that already described in the two tunnels, has plentiful fragments, up to six inches in diameter, of the Paleozoic shales and of Archean crystalline schists, the latter being derived from Canada by glacial transportation. Boulders of larger size are rare in this deposit. The effect of weathering is seen in the yellowish gray color of the upper 10 feet or more, but the lower part has the same dark bluish color as in the tunnels. In this clearly displayed and freshly undermined shore section an imperfect lamination is plainly observable throughout the upper part of the till to a depth of 15 feet or more, indicating that so much of the gravelly and stony clay, otherwise typical till, was laid down in the waters of the lake when it stood higher than now. To my mind this lamination, which is an almost universal feature of the superficial part of the till in Cleveland up to the highest ancient shore lines, seems to testify that at least the upper 15 to 20 feet of the till belonged to englacial and finally superglacial drift. If this part had been a subglacial deposit, amassed when the ice-sheet reached its maximum area or at any later time until the recession of the ice border past this vicinity, it could not have received so distinctive lamination, which is evidently due to the presence of water during its deposition, as of the lake held here by the retreating continental glacier.

This laminated upper portion of the till within the ancient lacustrine area, named by Logan and Newberry the "Erie clay," corresponds fully with the upper part, to about the same depth, of the smooth expanses of till within the areas of the glacial lakes Minnesota and Agassiz, held by the waning ice barrier respectively in the basins of the Minnesota river and the Red river of the North.

DELTA OF MODIFIED DRIFT AND ALLUVIUM.

Flowing from a reëntrant angle of the departing ice-sheet, shown by the course of its retreatal moraines as traced by Mr Frank Leverett, the head stream of the Cuyahoga river received a large tribute of modified drift, some of which was soon laid down as gravel and sand along the valley, while the fine sand and clay were borne forward to the Western Erie glacial lake, standing about 200 feet above the present lake level, and especially to the ensuing lake Warren, which held in succession three lower levels. With the modified drift, supplied directly from the ice melting, this river and its tributaries brought also much alluvium eroded from their channels and washed from the general surface of the drift sheet.

Only scanty delta deposits are found to have been made contemporaneous with the Leipsic beach, which was formed by the Western Erie lake. During the time of that beach the Cuyahoga river probably deposited nearly all its modified drift and alluvium along its valley, which appears to have required the greater part of that time to become filled along its south to north portion up to the Leipsic water level. Certain gravel and sand beds, however, underlain and overlain by till and stratified clay between the Forest City park and East Clark avenue, to be described later in detail, appear to be sublacustrine delta beds of Leipsic age.

Contemporaneous with the formation of the Belmore or first beach of lake Warren, an extensive tract of fine gravel and sand was spread in the lake upon the southern half of the site of Cleveland. At this time the Cuyahoga drainage basin was clad with a coniferous forest, from which trunks and branches of cedar, spruce, and pine, as determined by Whittlesey and Newberry, were swept by the river floods out into the lake, sinking waterlogged to the lake bed of till three to five miles beyond the mouth of the river as it was during that stage of the glacial lake, where now they are encountered at the base of the later delta sand in the northern part of the city.

During the stages of lake Warren marked by the lower Woodland Avenue and Euclid Avenue beaches, the deposition of the delta continued, its sand and silt being then wholly alluvium, supplied by the ordinary erosion of rains, rills, larger streams and the Cuyahoga itself in its gradual reëxcavation of the valley to keep pace with the declining levels of the lake, or, we may better say, with the progressive elevation of the land. This northern part of the delta covered the earlier driftwood and mainly attained, like the older southern part, a somewhat uniform depth of 10 to 20 feet, overlying the till and sloping, like that deposit, from south to north—that is, toward the lake—at a varying rate of 25 to 50 feet per mile.

The area of the Cuyahoga delta thus described is approximately coextensive with the city of Cleveland. It lacks, however, about two miles from reaching to the city limits on the west, being there bounded by a tract of till which is a continuation of the same topographic plain. On the southeast it fails of extending to the city boundary by about one mile, being succeeded by a somewhat rapidly ascending slope of till with rock beneath at no great depth, from Newburg to Kinsman street, beyond which, northeastward, the rising slope of till and rock outside of the delta and within the city limits is narrowed to a third or half of a mile in the vicinity of the Western Reserve University. Thence the delta continues east through Glenville and Collinwood, as extended by the prevailing eastward drift of the old glacial lake currents, which were caused by the winds to run like those of the present lake Erie The maximum width of the delta is about five miles, its length in the city of Cleveland, parallel with the lake shore, is eight miles, and its area, so far as it lies within the city, is about 25 square miles.

Recent undermining of the shore cliff by wave erosion along the distance of nearly a mile from the foot of Willson avenue east to Gordon park exhibits a continuous section of the delta sand, yellowish gray, horizontally stratified, 15 to 20 feet thick, separated by a definite level plane from the underlying dark bluish till, which holds abundant gravel and cobbles up to 3 or 4 inches in diameter, and occasionally of twice or three times that size, while larger boulders are absent or exceedingly rare. The cliff has a nearly constant height of 35 feet above the lake, and its lower half consists of this till, which also extends to much greater depth beneath the lake level. Through all the extent of the section the till is more or less clearly laminated from its top down to the shore, and in many places the laminæ show much contortion, although mainly they are horizontal. The inclosed stone fragments become more plentiful downward, but the lamination in general becomes less discernible in the same direction. My observations, as thus noted, indicate that the englacial drift here was not less than 15 or 20 feet thick. It was laid down as the laminated till in the water of lake Warren, about 150 feet deep. As no interbedding or blending of the till and the delta sand is anywhere seen, it appears certain that the delta deposition failed to extend so far until some time after the ice had retreated.

POSTGLACIAL EROSION.

Since the continuance of the glacial recession withdrew the northeast barrier of lake Warren, permitting that lake to be succeeded by lakes Algonquin and Lundy, the latter in a little time sinking to the small Champlain representative of lake Erie, which occupied only the northeastern part of the present lake basin, the Cuyahoga river, outflowing across many miles that are now the lake bed, to the early diminutive Erie, channeled quickly through the shallow delta and deeply into the till. The resulting crooked valley or trough has a width of one-third of a mile to one mile through the city of Cleveland, and is bounded by steep bluffs on each side which rise 100 to 150 feet (from north to south) above the river and its bottomland, the latter being 5 to 15 feet above the river and partly overflowed by its spring floods.

The river meanders along the flat bottomland, which is alluvium deposited by the stream during its slow uplift while the differential elevation of the land northeastward has caused the lake to extend southwestward and to rise gradually on all its southern shores. The alluvium earlier carried away by the river during its postglacial erosion was deposited in the central part of the present lake area, being there a delta of the smaller lake Erie, and the ensuing work of the river has been the partial refilling of the deep postglacial channel. In this process horseshoe-shaped moats have been left, cut off from the former winding course of the stream; and within apparently only a few centuries the river has repeatedly changed its lower course and its mouths, which became successively closed by the bars of the drifting beach shingle and sand. An old river channel, having such history, reaches a mile west from near the present mouth, and is now utilized with wharves on its sides for lading and unlading ships.

VALLEYS OF THE ROCKY RIVER.

RELATION AND CHARACTER OF THE TWO VALLEYS.

The next important tributary of lake Erie west of the Cuyahoga is the Rocky river, in Rockport township, which adjoins Cleveland. This stream entirely lost its valley by its being filled with drift and obliterated during the Ice age. We have, therefore, in this case two valleys, the preglacial one, with its very interesting drift section on the lake shore, and the postglacial wide and deep gorge, cut in the Erie shales.

The latter valley, if we could ascertain its average rate of cutting, would yield a measure of the Postglacial period; but this problem is not here considered. Indeed, nearly the same conditions may be said to be presented not less conveniently by many other streams of this region, from one of which, in Oberlin, Ohio, Professor G. F. Wright computes the duration of this period to have been between five and ten thousand years.

SIZE AND COURSE OF THE PREGLACIAL VALLEY.

Distinguished by its cliff section of drift uniform in height with the shale cliffs forming the lake shore on each side, the mouth of the preglacial Rocky river valley has a width slightly exceeding one mile, from about three-fourths of a mile to nearly two miles west of the present river's mouth, and between 8⅓ and 9½ miles west of the Public Square at the center of Cleveland. The course of this old valley has been carefully studied out and mapped, from well records and rock outcrops on either side, along all its extent through Cuyahoga county, by Dr D. T. Gould, of Berea, Ohio.* The preglacial river course, supposed to average about a mile in width, and in its last five miles probably reaching 200 feet or more below the level of lake Erie, is crossed by the present river about four miles above its mouth. Thence, in going up the Rocky river as it now flows, one travels at a distance of 1 to 2 miles west of the old valley along the next 10 miles to the south; but at a distance of about fourteen miles south of the lake Dr Gould believes that the preglacial and postglacial valleys coincide, their further upward extent for at least several miles to the southeast and south being the same.

COMPLETE FILLING OF THE PREGLACIAL VALLEY WITH DRIFT.

The Rocky river is a shorter and smaller stream than the Cuyahoga, their ratio as to area of drainage and volume of water being approximately the same as that of their preglacial valleys. How the ice-sheet acted to amass its drift in great depth, filling the old valley of Rocky river to its brim, so markedly in contrast with the glacial drift of the Cuyahoga valley, seems a difficult question. The drift so deposited in the mainly northwardly trending Rocky river valley is chiefly till or boulder-clay, and it was doubtless formed gradually as a subglacial deposit, excepting its upper part, as much, but probably not all, of the drift cliff on the lake shore. The trough-like valley appears to have slowly caught subglacial drift until it became filled; for the englacial and at last superglacial drift would be a rather uniform sheet, and the

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* Tract 70, in the Publications of the Western Reserve Historical Society, Cleveland, vol. ii, pp. 479–490, with map, Feb. 6, 1886.

drift above the shale on each side of the old channel has often no greater thickness than from 3 to 10 feet.

THE POSTGLACIAL ROCKY RIVER VALLEY.

Along its last five miles the present Rocky river flows in a gorge-like valley of postglacial erosion, from a sixth to a third of a mile wide and mostly 80 to 90 feet deep. On account of the lakeward slope of the general plain through which this gorge is channeled, its depth where it ends in the escarpment forming the south shore of lake Erie is reduced to 50 or 60 feet. It is cut down somewhat below the lake level along its last three-fourths of a mile, giving evidence that its erosion was far advanced before the relations of the land and the lake became as now. Another proof of this is the absence of a delta at the mouth, showing that the large mass of alluvium derived from the channeling of the valley was mostly borne forward by the stream flowing on what was formerly a land area to the central parts of the present lake bed.

At Scenic park, a pleasure resort on the bottomland of this postglacial valley in the southwest corner of section 23, Rockport, the east bluff is well covered by talus and trees; but the west bluff, at the base of which the river runs, is vertical, about 90 feet high, consisting wholly of shale, excepting 3 to 5 feet of till on its top. This locality is about three-fourths of a mile from the mouth of the river. The shale is a soft and easily eroded rock, scarcely more resistant to water-wearing and weathering than the usual boulder-clay or till; but the amount which the river has carried away is very impressive. At first thought it might seem to imply a geologically long postglacial period; but when the probable erosion of each year is made a divisor, the length of time required for the whole work is found to be only a few thousand years. During the recent time, comprising probably the greater part of this period, while the lake has held its present level, eroding the cliffs of all its south shore, as along the front of Cuyahoga county, the eastward shore currents and powerful waves of storms have swept away the delta tribute of both the Cuyahoga and Rocky rivers and the detritus furnished by the lake cliff erosion, bearing the alluvium and the detritus of the wave-cutting eastward and outward to be laid down on the shallow lake bottom.

Drift Sections.

LAKE ERIE CLIFF CROSSING THE PREGLACIAL ROCKY RIVER VALLEY.

The most interesting drift section found in the vicinity of Cleveland is the lake cliff along its extent of a little more than a mile where it crosses the drift-filled preglacial valley of the Rocky river, because it testifies of a glacial re-advance interrupting the general retreat. This section (figure 1) displays, along its eastern half, an underlying early till, which rises from below the lake level to a maximum height of 25 feet, declining westward and becoming hidden by the talus and finally sinking beneath the shore line. Next the section has, along all its extent, a stratum from 5 to 20 feet thick of mostly very fine sand, with scanty fine gravel, horizontally bedded, but often contorted in portions of small vertical range. No indication of erosion of the underlying till before the deposition of the sand, nor afterward of erosion of the sand previous to the deposition of the overlying till was anywhere detected. Very definite and mainly straight planes divide the lower till from the sand, and the latter from the till above it; but the upper till, which varies in thickness from 3 to 7 feet in its continuous extent through this mile, has a slightly uneven upper limit, overlain by a superficial deposit of sand. This sand and loam, forming the surface, is from 2 to 5 feet thick eastward, but attains a maximum thickness westward of about 15 feet.

FIGURE 1.—*Section on the Lake Shore across the preglacial Valley of Rocky River.*

A = lower till; *B* = interglacial sand; *C* = upper till; *D* = delta and alluvial sand; *E* = Erie shales. Length, 1⅙ miles; height, 40 feet.

No interbedding of the interglacial sand with the till below or above was seen. The three formations—lower till, intervening sand, and upper till—were evidently laid down in immediate succession, without transitional conditions, and with no intervals when the surface was land exposed to stream-wearing. Excepting the superficial delta or alluvial sand and loam, the whole section beneath consists of deposits made in the glacial lake between 200 and 150 feet deep overhead. The height of the section is quite uniformly about 40 feet above the mean surface of the lake. Irregularities of thickness of the several members, and their deviation from horizontality, are shown in figure 1; and we need only to add a few notes on the characters of the two till deposits.

Both the lower till and the upper till have abundant shale fragments, some of Paleozoic sandstones, and many of Archean crystalline schists. All these varieties range in size up to 6 or 8 inches. Boulders are very rare or wholly absent from nearly the entire section, except that many of Archean rocks, up to three feet in diameter, were seen in the lowest 5 or 6 feet of the lower till where it rests on the shale at the east side of the old valley. The lower till deposit has a dark bluish color through all its observed extent. Surface weathering and infiltration of water and air have caused the oxidation of the iron in the upper till and in the greater part of the interglacial sand, giving to them a yellowish gray color, along the east half of the section; but westward, where the upper till lies at a greater depth, both that and the sand beneath have the dark bluish unweathered color, and there the yellowish oxidized condition reaches only through the superficial sand.

The thinness and uniformity of the sheet of upper till, having only about a thousandth as much thickness as its length here exposed to view, yet uninterrupted across the preglacial valley, lead me to refer it to englacial drift of the temporarily re-advancing ice border. Probably a nearly similar or greater thickness of the upper part of the lower till was also englacial, being deposited by the ice during its first retreat. Lamination, however, is not very noticeable in either till.

The interglacial sand, which, like the two formations of till, seems referable to deposition in the water of the glacial lake, was examined in vain by Professor H. P. Cushing, of the Western Reserve University, and by the present writer, in search of traces of organic remains. This sand is doubtless modified drift that was supplied from the receding ice.

In the early history of military expeditions on lake Erie the mouth of the Rocky river and this neighboring drift cliff, with its sand and gravel beach, were remarkable as the scenes of wreck and disaster. The former locality, on November 7, 1763, witnessed the loss of nineteen bateaux, several officers, and sixty-three privates of Major Wilkins' expedition to the war against Pontiac and the French. Again, during the night of October 18 or 19 in the next year, 1764, a similar expedition, under Colonel (afterward General) Bradstreet, suffered great losses of bateaux, provisions, ammunition, and guns, by a sudden storm with high waves breaking upon them while encamped on McMahon's beach, at the foot of the drift cliff whose section has been here described.*

EAST SIDE OF THE CUYAHOGA VALLEY ON CLARK AVENUE.

Under the guidance of Mr Thomas Piwonka, of Cleveland, I examined a very interesting section of the drift forming the east bluff of the Cuyahoga valley on East Clark avenue and other sections of excavations to obtain clay for brick-making situated within three-quarters of a mile southward from that locality and within a half mile east of the immediate Cuyahoga valley. These excavations are on the upland expanse of glacial drift, mostly thinly covered by delta sand, upon which Cleveland is built.

A large main water pipe was laid during last summer across the valley

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*Chapter by Dr J. P. Kirtland in Whittlesey's Early History of Cleveland, 1867, pp. 97–129.

along Clark avenue, and its tunnel beneath the river has been already noticed. Where the water trench and cutting for street grading pass up the east bluff, the section (shown by figure 2) consisted of the following deposits, in descending order:

1. Sand and clayey loam, yellowish, forming the surface soil and extending to a depth of 2 to 5 feet.

2. Till, imperfectly stratified, yellowish, containing many small rock fragments up to 4 or 5 inches in diameter, within a short distance varying in thickness from 5 to 10 feet.

3. Sand and gravel, horizontally stratified, with occasional oblique bedding, yellowish above, gray below, mostly sand, but enclosing frequent thin gravelly layers with pebbles up to an inch or rarely two inches in diameter, about 25 feet.

4. Dark bluish clay, probably all more or less stratified, but scarcely discernibly so in the fresh excavation, containing only rare rock fragments up to 3 or 4 inches in diameter, 15 to 20 feet. This seems to represent the usually laminated and very pebbly upper part of the "Erie clay" or till.

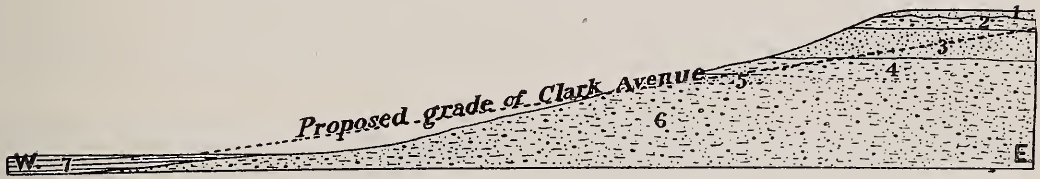

FIGURE 2.—*Section on Clark Avenue.*

Length, 800 feet; height, 125 feet.

5. Sand and fine gravel, of gray color, very distinctly horizontally stratified, having its upper two feet somewhat interbedded with the dark clay, six feet or more.

6. Till, probably forming the talus-covered lower part of the bluff; extending much deeper and tunneled beneath the river, underlying the shallow alluvium (7) of the bottomland.

The height of this bluff is about 110 feet above the bottomland and 125 feet above the river and lake. Its uppermost deposit of till is apparently correlative with the upper till of the Rocky river section, and both seem to me probably due to a moderate re-advance of the ice border when it formed the moraine which Mr Leverett has traced from this vicinity through Newburg and onward to the head of the Cuyahoga river. The next underlying sand and gravel appear to be a delta deposit carried into the lake to a considerable depth by this river during a part of the time of formation of the Leipsic beach.

In the brick-clay excavations noted as examined at a distance of one-fourth to three-fourths of a mile south of East Clark avenue Mr Piwonka and the writer found that the stratum numbered 2 is in some places typical till, with no marks of stratification, as was seen most notably close northeast of the railroad an eighth of a mile west of Petrie street. It there has a thickness of 10 to 12 feet, and along an extent of at least 200 feet it incloses very abundant rock fragments up to three or four inches in diameter, many others of larger size, and frequent boulders up to four feet in diameter, of all which a considerable proportion bear distinct glacial striæ. Under the till of that excavation, and divided from it at a definite level plane, is the stratified sand and fine gravel of number 3. Again, the same thin sheet of true till, with occasional Archean boulders up to five feet in diameter, was seen on two large plateau areas in the northeast angle of Independence and Bading streets, on the opposite side of this railroad and an eighth to a fourth of a mile southwest of the foregoing place. Both of these till deposits are probably a part of the westward extension of the Newburg moraine.

Most of the excavations for brick-making, however, which are numerous within a third of a mile southeast and south of these localities, have no well defined till, but instead the stratum number 2 of the Clark Avenue section is represented by a thickness of 15 to 20 feet of compact, dimly stratified clay, holding no boulders, only very rare small stones, and no perceptible gravel or sand. This bed reaches eastward beyond Petrie street and south to the Forest City park, as revealed in pits for brick-making; and ditches for laying water pipes show it to continue as the surface formation at least about a mile farther south, to the vicinity of the intersection of Independence and Harvard streets.

FIGURE 3.—*Section from the Leipsic Beach and Big Creek north along Gordon Avenue to the Lake.*

1. Leipsic beach. 2. Belmore or Sheridan beach. 3. Upper Crittenden or Woodland Avenue beach. 4. Lower Crittenden or Euclid Avenue beach.

SOUTH-TO-NORTH SECTION IN THE WEST PART OF CLEVELAND.

The relationships of the shale, which is the bed rock, the till, and the delta, together with the four beaches which will be presently described, are shown by the accompanying section (figure 3), drawn from south to north across Big creek and along Gordon avenue to the lake. Its length is about four miles, the lakeward descent in this distance being about 200 feet.

FROM NEWBURG NORTHWEST TO LAKE ERIE.

Similarly, figure 4 presents a section from Newburg (now annexed to Cleveland) northwestward nearly along Broadway and Erie streets to the lake, a distance of six miles, with a descent of about 250 feet. Of necessity the scale of height in this figure, as in those preceding, is greatly exaggerated, in order to give sufficient distinctness to the several thin drift and delta deposits.

ALTITUDES IN CLEVELAND FROM THE CITY SURVEYS.

For my aid in the observations and studies here presented, Mr C. G. Force, chief assistant city engineer of Cleveland, has supplied the following altitudes, determined by leveling. They are given in feet and are referred to mean tide sea level, according to my work as published in Bulletin 72, United States Geological Survey, 1891, pages 15, 147:

Zero reference of Cleveland city levels (high water of lake Erie in 1838), 575.20.

Lake Erie (maximum depth, 210 feet), lowest stage at Cleveland (in 1819), approximately, 570; highest stage (in 1838), 575; mean annual low and high stages, 571–574; mean surface, January 1, 1860, to December 31, 1875, 572.86.

Intersection of Detroit and Seward streets, near St. John's hospital, 669; of Detroit and Taylor streets, 677; of Detroit and Pearl streets, 669.

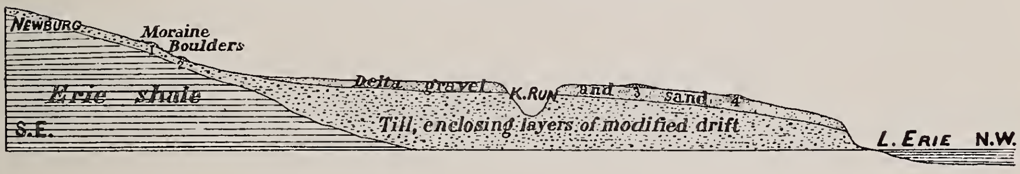

FIGURE 4.—*Section from Newburg northwest through the central Part of Cleveland.*

1, 2, 3, 4. Successively, the Leipsic, Belmore, and Upper and Lower Crittenden beaches. K. Run. Kingsbury run.

Intersection of Superior and Ontario streets, center of the Public square, 656.

Euclid avenue at the southeast corner of the Public square, 665.

Intersection of Euclid avenue and Erie street, 661; of Euclid and Willson avenues, 665; of Euclid and Madison avenues, 673; of Euclid avenue and Doan street, 684.

Euclid avenue at Coltman and Carabella streets (at entrance to Lakeview cemetery), 691.

West Madison avenue at Ridge avenue, 690.

Courtland street at Duke street, 687.

Lorain street at Rockport depot (South street), 781; at Highland avenue, 772; at the west end of Denison avenue, 739; at Ridge avenue, 699; at Harbor street, 688; at Pearl street, 684.

Clark avenue at Ridge avenue, 698; at Burton street, 681; at Pearl street, 683; at Jennings avenue, 684.

Denison avenue at Lorain street, 739; at Minton street, 739; at Ridge avenue and the bridge over the Chicago, Cincinnati, Cleveland and Saint Louis railway, 744; at Ritchie street, 738; at Wyoming street, 728; at Pearl street, 690.

Harvard street at Reade street, 745; at Bissell street, 759.

Union street at Wageman street, 742.

Woodland Hills avenue at Kinsman street, 783; at South Woodland avenue, 779; at North Woodland avenue, 741; at Quincy street, 723.

Woodland avenue at Perry street, 676; at Willson avenue, 675; at East Madison avenue, 684.

Surface of the ground at the Garfield monument, 822.

Fairmount reservoir, bottom, 725; low and high water stages, 739–745; the walk on the top of the embankment, 750.

High Service reservoir on Kinsman street, bottom, 877; water surface, nearly constant, 900.

Beach Ridges in Cleveland.

RELATION OF THE BEACHES.

On the accompanying map of the city of Cleveland (plate 15), the courses of the four ancient shore lines which are traceable through the city are delineated. Surveys and investigations of the Pleistocene glacial lakes of the Saint Lawrence basin by Whittlesey, Newberry, N. H. Winchell, Gilbert, Spencer, Taylor, Leverett, and others show that the uppermost beach seen at Cleveland is a continuation of the Leipsic beach ridge (named by Winchell in northwestern Ohio), which is the second of the two shore lines formed by the Western Erie glacial lake outflowing at Fort Wayne, Indiana, to the Wabash river; and that the three lower beaches are shores of the glacial lake Warren, which outflowed at Chicago to the Des Plaines and Illinois rivers, attaining in its maximum extent an area that included the present lakes Superior, Michigan, Huron, and Erie.*

LEIPSIC BEACH OF THE WESTERN ERIE GLACIAL LAKE.

In Rockport and Brooklyn townships the Leipsic beach extends from about a half mile north of Rockport station of the Lake Shore and Michigan Southern railway, east and southeast to the southern edge of Brooklyn village, and onward across the Independence road, about a half mile southeast of that village and a third of a mile south of the cemetery, to the west side or brink of the Cuyahoga valley. The southwest boundary of Cleveland lies a half mile to one mile northeast of this shore.

North of Rockport station the Leipsic shore is marked by two beach ridges of gravel and sand, at nearly the same level, each rising 3 to 6 feet above the expanse of till on the south and north. Crossing Lorain street, one and a half miles east-northeast of Rockport station, this shore is a terrace eroded in the till, having a descent of 20 feet toward the northeast within 15 or 20 rods, and bearing 5 to 8 feet of gravel on its top. The same wave-cut terrace, though becoming less conspicuous, continues

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* The relations of these lakes, and of others succeeding them, held by the receding ice-sheet in the Saint Lawrence basin, are discussed by the present writer in the American Journal of Science, III, vol. xlix, pp. 1–18, with map, Jan., 1895.

southeasterly across the Chicago, Cleveland, Cincinnati and Saint Louis railway (a mile northeast of Linndale station) to the valley of Big creek. Beyond this creek, which was thought by Mr Leverett to mark the east termination of the Leipsic beach, I discovered its continuation, defined by a terrace cut in the till with moderately sloping descent of 5 to 15 feet, accompanied in part of its course by a ridged gravel and sand deposit, the latter being observed a half mile south of Brooklyn post office and continuously onward for three-fourths of a mile or more to the southeast. The gravel beaches and eroded terraces of this shore, at their crests, are 190 to 200 feet above lake Erie; and the level of the Western Erie glacial lake, at the time of their formation, was approximately 185 feet above the lake, or 760 feet, nearly, above the sea.

East of the Cuyahoga river, the Leipsic shore, marked by two little sand and gravel ridges, nearly parallel and 25 to 50 rods apart, differing about 10 feet in altitude, each raised 2 to 5 feet above the surface of till, I have traced and mapped from the east side of the Brecksville road, three-fourths of a mile south of the city limits, northward across Harvard avenue (between Reade and Bissell streets) to the Broadway School. Next this shore is found marked by a single small beach ridge running almost due north between Upton street and Woodland Hills avenue, being there distinctly observed for a half mile, from Union street to Harris avenue, on which, close south of the southern branch of Kingsbury run and 10 to 20 rods west of Niagara street, it has a typical beach ridge of coarse wave-worn gravel, 1 to 2 feet above the surface of till on the east and 5 feet above that on the west, the width of the ridge being 10 or 12 rods. This place is a mile north of the belt of very abundant boulders on Marble, Cottage and Fayette streets, which represent one of the chief lines of deposition, probably the most northern, of the Newburg moraine. Farther northeastward, the Leipsic shore is doubtless traceable to the moraine described and mapped by Leverett from Euclid eastward parallel with the present lake Erie shore.

The crests of the two Leipsic beach ridges east of the Cuyahoga valley, in their northward course to Harvard street, are about 190 and 180 feet above lake Erie, corresponding to old lake levels at 185 and 175 feet nearly. The single beach farther north, as at Harris avenue, seems probably the representative of the lower one farther south, and of the time when the lake cut the lowest part of the conspicuous terrace on this shore northwest of Big creek.

BELMORE OR SHERIDAN BEACH OF LAKE WARREN.

The earliest shore line formed in the basin of lake Erie after the water level fell below the Wabash outlet was named by N. H. Winchell the

Belmore ridge. It appears to be continuous with Spencer's Ridgeway beach northwestward, and with the Sheridan beach of Gilbert and Leverett eastward.

About one and a quarter miles north of Rockport station, and a half mile north of the Leipsic shore, this Belmore beach curves from a northeastward to an easterly course, nearly coinciding there with the Warren road and Linn street. Thence it passes east-southeastward, crossing Lorain street at the beginning of Denison avenue. Here and onward for two miles Denison avenue runs on the top of its massive ridge of sand and gravel, which is 10 to 20 feet high above the smooth expanse of till on each side, with a width of 20 to 30 rods between the bases of its slopes, and with a smoothly rounded or nearly flat top from 5 to 10 rods wide.

Turning more southward, this beach ridge leaves Denison avenue close east of Wyoming street, and at a short distance farther it is cut through by the deep and wide postglacial valley of Big creek, whose sides, to within 10 or 15 feet below their top, are shale. Continuing through Brooklyn village, this wide sandy ridge is the site of Mechanic and Broad streets and passes onward through the cemetery.

On the east side of the Cuyahoga valley the conspicuous Belmore ridge of sand and gravel begins close east of the Independence road, two miles west-southwest of Newburg. A half mile northeastward it forms an exceptionally high knoll, about 30 feet above the general level, crowned with an oak grove. Running thence northeasterly, this massive beach ridge crosses Harvard street just west of the Newburg riding park; it is less prominent where it intersects Broadway at the South High School, but at some points onward in its course to Union street at the south end of East Madison avenue, and to Kinsman street at Fairview avenue, it rises as a well defined sand ridge, very distinct from the till on each side. Becoming farther on mainly a moderately sloping terrace of erosion, it is crossed by the Woodland Hills avenue between North Woodland avenue and Ingersoll road. Its farther course northeastward, in the vicinity of the Western Reserve University and Lakeview cemetery, is much obscured by the ravines which cut through the thinly drift-covered shale bluffs.

From the crest of these bluffs, on a level with the base of the Garfield monument and overlooking the Cuyahoga embayment and delta and the city of Cleveland, there extends away southeastward a nearly level or moderately rolling plateau of shale, with thin glacial drift, about 250 feet above the lake. These grand topographic features seem due almost wholly to preglacial subaërial erosion, in a small degree modified by glacial erosion, but not affected by any lacustrine agencies.

The crest of the Belmore beach on Denison avenue, and in its higher parts east of the river, excepting only the oak-covered knoll, is 165 to 170 feet above lake Erie, corresponding to a former lake level at 160 to 155 feet, being thus approximately 730 feet above the sea.

LOWER BEACHES OF LAKE WARREN.

Third or Woodland Avenue beach.—Derived by eastward shore currents from a wave-eroded surface of till with many large boulders, the third of the Cleveland beaches, in their descending order, becomes well developed close southeast of the intersection of West Madison avenue and Berlin street as a ridge of very coarse gravel and sand, which, mostly 3 to 5 feet high and 10 to 15 rods wide, runs thence three-fourths of a mile east-northeast to the Waverly School. Farther eastward this shore deposit becomes wholly sand and is spread in a smooth swell 20 to 40 rods wide, rising only two or three feet above the general expanse of the delta southward. This phase of the old shore is crossed by Courtland street, and St. Stephen's church, near Duke street, is on its highest part. Onward east-northeasterly similar indistinct evidence of shore action during the deposition of the delta is observable along the course of Lorain street, and, east of the Cuyahoga, along an east-southeasterly course lying close south of Woodland avenue for a distance of nearly three miles, excepting that in the vicinity of Willson avenue the low beach crest passes for a half mile close along the north side of Woodland avenue. Along a distance of 40 rods next west of the workhouse, in the southwestern angle of Woodland and East Madison avenues, this shore is conspicuously defined by a beach ridge of sand and gravel four to eight feet above the adjoining delta level.

The crest of this beach, where it is well developed, is 115 to 120 feet above lake Erie, and the surface of lake Warren at its time of formation was at 112 to 115 feet, nearly, or about 685 feet above the sea. If we may judge from the well marked shore erosion and beach accumulation by the lake at this height in Cleveland, a shore line continuing from this may be expected to be traceable long distances both to the west and east.

Fourth or Euclid Avenue beach.—Passing through the city of Cleveland, nearly along the course of Detroit street and Euclid avenue, the fourth definite shore line of this part of the lake Erie basin is marked along its course of nearly ten miles in this city by a continuous beach ridge of sand and fine gravel, excepting where it is lost for nearly a mile by the postglacial erosion of the Cuyahoga valley. On Detroit street, or within a few rods either north or south, this shore has usually a small beach ridge or often two, and immediately to the north there is also in part of this extent a terrace cut by waves in the till, with a somewhat steep descent of 10 or 15 feet. At St. John's Hospital the principal beach ridge, raised 3 to 5 feet above the general surface of the till, lies about 20 rods south of Detroit street, and has a width of 6 to 10 rods. Its gravel, stones and cobbles vary in size up to 6 or 8 inches in diameter. From the junction of Lake avenue and Detroit street eastward this shore lies on the Cuyahoga or Cleveland delta sand plain to the limits of the city and beyond. It passes close south of the public square, by the intersection of Prospect and Erie streets, and thence coincides nearly with the course of Euclid avenue, the crest of its broad, massive swell being at first south, but soon and for a long distance close north of this most beautiful avenue. In the vicinity of Wade park the beach swell, like a huge low wave, runs a fourth of a mile, more or less, northwest of Euclid avenue and nearly parallel with it. The crest of the beach varies from 95 to 100 feet above the lake, having been formed when the glacial lake Warren held a slightly varying plane (in low and high stages and in calm and storms) at 90 to 95 feet, or 665 feet, very nearly, above the present sea level.

The Euclid Avenue beach marks the principal and lower one of the two or more parallel and companion shores which Leverett groups together as the Crittenden beach, so named by Gilbert from Crittenden in southwestern New York, near which this shore has its eastern land termination, the country farther east and north having been enveloped by the waning ice-sheet. In Cleveland the third or Woodland Avenue beach, before described, is the upper member of the compound Crittenden levels; but there appears to be sufficient reason for considering these two shores separately, as they are divided by a vertical interval of 20 to 30 feet along the whole extent of the south side of lake Erie.

CORRELATION WITH STAGES OF THE GLACIAL RECESSION.

The foregoing description of the Leipsic beach shows that the time of its formation extended through that of the Newburg moraine and probably up to the time of the Euclid moraine. In two very valuable contributions to the glacial geology of this region,* Mr Leverett has proved the successive glacial lake stages to have been contemporaneous with stages of the glacial retreat defined by four distinct moraines. The Leipsic beach he supposed to have been wholly formed before and during the accumulation of the Newburg moraine, which he thought to be represented by the moderately rolling and hilly surface of till a half mile to one mile south of Brooklyn. This area may so represent the moraine, or at least a southern branch of it, but doubtless much or nearly all of its

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*Am. Journal of Science, III, vol. xliii, pp. 281-301, with maps, April, 1892; vol. l, pp. 1-20, with map, July, 1895.

prominence is due to the preglacial contour of the bed-rocks. From Big creek westward, the Leipsic shore displays perhaps three or four times more wave-cutting and resultant beach gravel and sand than in the vicinity of Brooklyn and east of the Cuyahoga valley. There, however, it is unmistakably continued northeastward beyond the more northern deposits of the Newburg moraine, so that the later part of the Leipsic shore work was done after the ice sheet had receded from its Newburg boundary.

The stages of recession of the ice contemporaneous with the Belmore and lower beaches are recorded by moraines, as mapped by Leverett, passing from west to east and southeast near Hamburg and Lockport, N. Y., from which they may be conveniently named, the Hamburg moraine and the Belmore or Sheridan beach, and later the Lockport moraine and the Crittenden beaches, being respectively correlative. No well defined shore of lake Warren is found below the Euclid Avenue or principal Crittenden beach.

Temporary Re-advances of the Ice-sheet.

AT THE MOUTH OF ROCKY RIVER AND IN CLEVELAND.

With the descriptions of drift sections already given, only a few words are needed here to direct attention to the clear evidence of a temporary re-advance, interrupting the general departure of the ice, shown by the relations of the series of glacial and modified drift formations in Cleveland and its vicinity. Apparently just before the accumulation of the Newburg moraine, the ice border for a short time moved forward over a tract which it had just previously relinquished, forming by this re-advance the uppermost deposit of till in the old valley of the Rocky river and on East Clark avenue and southward in Cleveland. The Rocky river section indicates that the fluctuating ice-front was all the while bounded there by the glacial lake.

AT TORONTO AND SCARBORO', ONTARIO.

About 160 to 170 miles northeast from Cleveland the deposits of glacial and modified drift and alluvium in Toronto and Scarboro', Ontario, as described by Prof. A. P. Coleman,* record a more complex history of glacial re-advance during the time of general retreat. Studying the sections of till and interglacial fossiliferous beds given by Coleman, with their evidences of stream erosion before the deposition of the till next above the thick stratified sand and clay which contain remains of a temperate

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*Am. Geologist, vol. xiii, pp. 85–95, February, 1894; Journal of Geology, vol. iii, pp. 622–645, with sections, September–October, 1895.

fauna and flora, I attribute that glacial re-advance to a time after the glacial lake Iroquois in the lake Ontario basin began to outflow eastward by Rome to the Mohawk and Hudson. After the deposition of the fossiliferous sand and clay beds of the Scarboro' section in the gradually shallowing water of lake Warren or of the succeeding glacial lakes Lundy or Newberry, this outflow east from the Ontario basin began. On account of the depression of the land which brought on this final Champlain epoch of the Ice age, the relative height of the land in the vicinity of Toronto, as compared with the depressed region about 190 miles eastward at Rome, then permitted a stream to erode its valley near Toronto to a depth below the present level of lake Ontario. Later, and after a temporary advance and second retreat of the ice border at Scarboro' and Toronto, forming a thick till deposit, the differential re-elevation of the land, probably 200 to 300 feet more at Rome than in the western part of the Ontario basin, caused the water level of lake Iroquois to rise gradually on the land westward until it stood at last permanently during many years at the conspicuously developed Iroquois beach.

The uppermost till of the Scarboro' Heights—that is, the second till deposit above the fossiliferous beds—seems to be a retreatal moraine, belonging to the second glacial recession, or to a third retreat after a second slight re-advance, all considerably antedating the Iroquois beach, which lies above all these drift accumulations.

Climatic Conditions of the Champlain Epoch.

The glacial and interglacial deposits thus found on the shore of lake Ontario seem to me wholly referable to a portion of the time of general glacial retreat subsequent to the Rocky river and Cleveland drift sections. In these sections no evidence was obtained concerning the plant and animal life of the adjoining land or of the glacial lake, referable to so early a date as the Newburg moraine and time of formation of the upper till in the sections specially noted. What the climatic conditions were, and the incoming fauna and flora, may, however, be partially suggested by the Toronto and Scarboro' sections, where we see that the interval between the formation of successive and superposed till deposits had a temperate climate nearly like that of the same district to-day.

The predominantly wasting ice border rose probably to an altitude of 5,000 feet within 100 miles from its edge while being dissolved by the warm Champlain climate with somewhat lower altitude of the land than now. If the retreat of the ice-sheet from the northern United States and Canada occupied, as I think, some three to five thousand years, disappearing earliest from the upper Missouri and Mississippi basins, and latest from New England, the province of Quebec, and Labrador, the extension of a warm temperate flora and fauna could well keep pace with the glacial recession, so that, as on the waning Malaspina ice-sheet, a flora like that of the same latitude today, and concomitant temperate molluscan and insect life, may well have thrived up to the very boundary of the ice, or perhaps in the case of the plants and insects even extending, as in Alaska, upon the drift-covered ice border.

Darwin noted, in his narrative of the voyage of the *Beagle*, that glaciers in the fiords of southern Chile reach down to the sea level within nine degrees of latitude from where palms flourish. Professor W. O. Crosby tells me of his observations of fine orchards of cherries and other fruits cultivated close to the limits of the large local fields of ice and névé in Norway, one of which has an area of about five hundred square miles. In the Alps the glaciers end only a few hundred feet from productive fields and gardens of flowers. Still more like the condition of North America and Europe during the recession of their Pleistocene ice-sheets is the vast fertile plain of India, enjoying a tropical climate, while within a short distance along its northern side, and farther west and east for an extent of 1,500 miles, runs the almost impassable Himalayan range, with valleys bearing glaciers and summits crowned with perpetual snow.

The proximity of the very cold Himalayas does not bring frosts to the neighboring tropical plain. In like manner the ice-sheet still lingering on northern Ontario, New York, and New England, did not cause a very frigid climate to prevail in the winters, nor nights of frost in the summers, on the windward low region of the Laurentian lakes whence the ice had recently retreated.

At a somewhat later time than that represented by the Toronto and Scarboro' fossiliferous modified drift, when the ice-sheet had so far receded as to uncover the Ottawa and Saint Lawrence valleys, which then became filled with the far more extensive gulf of Saint Lawrence to lake Champlain, almost to the mouth of lake Ontario, and to Allumette island of the Ottawa river, 75 miles above the city of Ottawa, the presence of a flora including forests, and a marine fauna, nearly like those of today in the Saint Lawrence region, is known, as so fully described by Sir William Dawson in his recent work, " The Canadian Ice Age," and in his many earlier papers, by their remains in the Leda clays and Saxicava sands, deposited during the short interval between the glacial retreat and the reëlevation of the land from its Champlain subsidence.

In a limited sense the Toronto fossils may be called interglacial, as the term is used in the present paper, since they lie between deposits of glacial drift; but they seem better referred to moderate oscillations of the ice boundary during its general retreat after the Iowan stage of the Glacial period, that is, to a time during the Wisconsin or moraine-forming stage, rather than to the distinct glacial epochs which Coleman infers from them. The evidence of two closely consecutive glacial recessions and re-advances in Scarboro' and the thinning out of the thick deposits of till so formed within a few miles westward imply that the ice border during that whole time was near, but seem quite inexplicable on the hypothesis that these till formations record great re-advances of the ice, as either to the Iowan stage or to the Wisconsin moraines. Furthermore, the thick Scarboro' stratified beds were evidently amassed as deltas, and the origin of so large a supply of sediments seems referable only to their derivation chiefly from englacial drift exposed by ablation on the margin of ice-fields within the drainage area of the delta-forming streams. In this tract of confluence between the great eastern and central lobes of the Laurentide ice-sheet, represented by the angle of the drift boundary at Salamanca in southwestern New York, there undoubtedly was brought an exceptional volume of the englacial drift by the confluent glacial currents.

The Ice age is found divisible into two parts or epochs, the first or Glacial epoch being marked by high elevation of the drift-bearing areas and their envelopment by vast ice-sheets, and the second or Champlain epoch being distinguished by the subsidence of these areas and the departure of the ice, with abundant deposition of both glacial and modified drift. Epeirogenic movements, first of great uplift and later of depression, are thus regarded as the basis of the two chief time divisions of this period. Each of these epochs is further divided in stages, marked in the Glacial epoch by fluctuations of the predominant ice accumulation, and in the Champlain epoch by successively diminishing limits of the waning ice-sheet, which, however, sometimes temporarily re-advanced, inclosing stratified and fossiliferous beds between the unstratified glacial deposits.

THE GREAT DIKE IN MEDFORD, MASSACHUSETTS

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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DISINTEGRATION AND DECOMPOSITION OF DIABASE AT MEDFORD, MASSACHUSETTS

BY GEORGE P. MERRILL

(Presented before the Society December 26, 1895)

CONTENTS

INTRODUCTION.

In the paper herewith presented the writer has endeavored to illustrate the chemical and physical changes taking place in the breaking down of rock masses through the ordinary conditions of atmospheric action commonly grouped under the name of weathering. The general tendency of the investigations has been the same as those pursued in the case of the disintegrated granitic rocks of the District of Columbia, the results of which were presented to the Geological Society of America at its meeting in Baltimore one year ago.*

DESCRIPTION OF LOCALITY.

The rock selected for investigation in the present instance is a coarsely crystalline, somewhat granular diabase, which occurs in the form of a large dike exposed almost continuously from the Mystic river, in Medford, Massachusetts, northward toward Spot pond, for nearly two miles.

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* Bull. Geol. Soc. Am., vol. 6, March, 1895, pp. 321-332.

Its maximum breadth is stated to be not less than 500 feet, but it narrows gradually northward to a diameter of not above 50 feet. A mile south of the Mystic, on the same north-and-south line, is the so-called Powder House dike of the same character, and presumably but a continuation of the one at Medford. In point of age the dike is one of the youngest of rocks of the vicinity, cutting the older eruptives, granite, "felsites" and diorites, as well as the Carboniferous slates and conglomerates.

PETROGRAPHIC FEATURES OF THE ROCK.

The general petrographic features of the dike have been well described by Dr William H. Hobbs, on whose paper* I shall draw for a description of the material in its least changed condition. The rock is quite uniform in general character and for the most part sufficiently coarse in crystallization to permit the ready determination by the unaided eye of its chief constituents, plagioclase feldspar, augite, biotite and occasional pyrite. Microscopical and chemical tests indicate the presence of two feldspars, the one labradorite and the second a more acid variety, presumably orthoclase. Original apatite, magnetite and ilmenite occur, and secondary hornblende, chlorite, quartz, calcite, leucoxene and pyrite. The chemical composition of the rock is to be noted later.

EARLIER REFERENCES TO THE DISINTEGRATION.

That this diabase had undergone extensive disintegration was sufficiently evident to have attracted the attention of the earlier geologists, who indeed could scarcely fail to note so striking a feature in a region which had been subject to extensive glaciation, and where as a consequence only the small amount of residuary material from rock decomposition that has been formed since glacial times is now to be found in place.

The first and most detailed description of this phenomenon I have been able to find is that given by J. F. and S. L. Dana,† who state that—

> "At Powder House hill, in Charleston, in the center of Medford, in Reading and in Woburn the greenstone is most completely disintegrated, and forms a beautiful reddish brown sand which is much employed for forming hard gravel walks. At these places the greenstone occurs in large globular masses, with a solid nucleus surrounded by concentric lamina of greenstone in various stages of decomposition. The lamina are of various thickness and are often easily separated. It bears some resemblance to that variety of secondary greenstone called globular

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* Bull. Mus. Comp. Zoölogy, vol. xvi, no. 1, 1888.

† Outlines of the Mineralogy and Geology of Boston and Vicinity, Mem. American Academy of Arts and Sciences, vol. iv, 1818, p. 200.

rock. Globular masses appear piled on each other like stones in a wall, and the interstices are filled with the above-mentioned reddish sand. The external surface of the greenstone frequently presents a rusty brown color, which arises from the decomposition of the imbedded sulphuret of iron. The oxide of iron is found in various states and of various colors in the same specimen. Near the surface it is yellow and pulverulent; interiorly it is more compact and its color is reddish brown and often of a bright vermillion. When by exposure to the atmosphere the sulphuret of iron is not only decomposed but removed, the surface of the rock becomes cellular, and thus much resembles some varieties of lava. Such specimens are characterized by their difficult frangibility, toughness and by the dark green color and crystalline structure of the feldspar, which are very evident in the compact center of these masses."

The general description as above given is sufficiently detailed and charactistic for our present purposes, though the cellular rock, due to oxidation and removal of the pyrites, has not come under my observation. The color of the sand resulting from the decomposition is, further, by no means due wholly, if at all, to the sulphuret of iron, but rather to the decomposition of ferruginous silicates, such as mica and augite.

PRESENT ASPECT OF THE DIKE.

The general aspect of the dike, as recently exposed a few rods north of the intersection of Mystic and Main streets in Medford village, is shown in the accompanying plate (16) from a photograph, for which I am indebted to Professor W. O. Crosby, as I am also for the samples of fresh and disintegrated material utilized in the analyses and the general facts regarding its occurrence. The still sound, boulder-like masses, some in place and others rolled to the bottom of the cutting made in excavating, are plainly evident, and the statements made by the Messrs Dana 78 years ago, though descriptive of another locality, are almost equally applicable here. In the upper left portion of the view the disintegrated rock is seen overlain by glacial till, a feature to which I shall refer again later.

MECHANICAL ANALYSIS OF DISINTEGRATED ROCK.

In order to first ascertain the physical changes which had taken place in the breaking down, the resultant sand was submitted to a process of sifting and washing, yielding the results given below, and for which I am indebted to Professor Milton Whitney.*

Of these separations, those represented by numbers 1 and 2 are plainly, even to the unaided eye, of a compound nature, and easily recognizable as diabasic derivatives, though somewhat discolored by iron oxides.

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* In charge of the Division of Agricultural Soils, Department of Agriculture.

Number 3 shows particles of feldspar, augite and mica fairly well disaggregated, though even here many of the granules are compound. Number 4 differs mainly in being finer and of a lighter color, while 5, of a rich mahogany brown color, appears to the unaided eye to be composed mainly of mica scales. The microscope, however, shows it to contain numerous badly stained but quite fresh feldspathic particles and cleavage flakes of augite. Number 6, the particles of which lie between .1 and .05 of a millimeter in diameter, shows also only minute flecks of mica recognizable macroscopically, but contains both feldspathic and augitic particles like number 5, while 7 and 8 are deep ocherous brown silts, offering no distinctive features to the unaided eye, and 9 would pass for a light brown ocher. The material analyzed as silt (columns 5, 6 and 7 below) is the equivalent of numbers 7, 8 and 9 of this series.

Name.	Diameter of particles.	Per cent.
1. Gravel	Above 2. mm.	42.3
2. Fine gravel	2. –1. mm.	20.66
3. Coarse sand	1. – .5 mm.	12.72
4. Medium sand	.5 – .25 mm.	9.37
5. Fine sand	.25 – .1 mm.	4.97
6. Very fine sand	.1 – .05 mm.	4.18
7. Silt	.05 – .01 mm.	1.13
8. Fine silt	.01 – .005 mm.	0.37
9. Clay	.005– .0001 mm.	1.67
10. Loss at 110°		0.66
11. Ignition		1.73
Total		99.76

Chemical Analyses and their Discussion.

The chemical nature of the fresh and decomposed rock is shown in the accompanying table, the results being in nearly every case averages obtained from two or more analyses. The "fresh" material, obtained from the interior of one of the boulders, is firm in texture, has a bright, clean fracture and shows to the unaided eye no signs of decomposition. When pulverized and treated with acid, however, it effervesces distinctly, indicating the presence of free carbonates, which are also observable as secondary calcite when thin sections are examined under the microscope. Some of this calcite is evidently a deposit from infiltrated waters, being derived from the surrounding decomposed material, while a portion results from the decomposition of the silicate minerals in place. Aside from a slight kaolinization of the feldspars and development of chlorite from the ferruginous silicates, there are no other observable signs of decomposition, though the presence of a soda-bearing zeolite is indicated by cubes of chloride of sodium, which separate out when an uncovered slide is treated with a drop of hydrochloric acid.

Analyses of fresh and disintegrated Diabase from Medford.

	Fresh diabase.		Disintegrated diabase.		Silt from disintegrated diabase, numbers 7, 8 and 9 of table, on p. 352.		
Constituents.	1 Bulk analysis.	2 Analysis of portion soluble in HCl and Na_2Co_3.	3 Bulk analysis.	4 Analysis of portion soluble in HCl and Na_2Co_3.	5 77.87 per cent soluble in HCl and Na_2Co_3.	6 22.13 per cent insoluble in HCl and Na_2Co_3.	7 Total.
SiO_2 in HCl	47.28	1.19	44.44	0.85	0.47	13.51	36.61
SiO_2 in Na_2Co_3		9.66		8.65	22.63		
Al_2O_3	20.22	4.74	23.19	4.86	21.98	5.88	40.68
Fe_2O_3	3.66	10.91	12.70	10.00	12.83		
FeO	8.89						
CaO	7.09	3.09	6.03	1.50	3.32	0.12	3.44
MgO	3.17	2.20	2.82	1.84	3.23	0.79	4.02
MnO	0.77	Not det.	0.52	Not det.	Not det.	Not det.	Not det.
K_2O	2.16	1.21	1.75	0.68	1.30	0.52	1.82
Na_2O	3.94	0.50	3.93	0.17	0.90	1.24	2.14
P_2O_5	0.68	Not det.	0.70	Not det.	Not det.	Not det.	....
Ign.	2.73	2.73	3.73	3.73	10.86	0.11	10.97
	100.59	36.23	99.81	32.28	77.52	22.17	99.68

A glance at this table is sufficient to show that the disintegration is accompanied by decomposition and a leaching action which has resulted in the removal of a portion of the more soluble constituents. The fact that the fresh rock yields the larger percentages of its constituents to the solvent action of acid and alkaline solutions is readily explained on this ground, though I doubt if the full significance of the fact, so far as it relates to silicious crystallines, is as yet appreciated. It will be observed that 36.23 per cent of the fresh rock and 32.28 per cent of the decomposed is thus extracted.

Of the material classed as silt in columns 5, 6 and 7, or as silt and clay, by Professor Whitney, on page 352, and which constitutes only some 3.17 per cent of the entire residual debris, 77.87 per cent is soluble in dilute hydrochloric acid and sodium carbonate solutions. The insoluble portion, constituting 22.13 per cent of the silt, consists of unaltered feldspars and iron, lime and magnesian silicates, which are easily recognizable under the microscope in minute, sharply angular particles. This portion of the separation is of interest as showing the minute stage of subdivision attainable without complete decomposition in deposits where no mechanical forces are operative other than those involved in hydration and temperature changes. The bearing of this upon the origin of the materials forming loess and such secondary rocks as the shales and finer sandstones, I cannot but regard as of some importance.*

It is, however, obvious to all who have given the subject attention that chemical analyses alone, as ordinarily set forth, convey a very imperfect idea of the actual changes which have gone on in the process of weathering. Indeed, the proper interpretation of such analyses is attended with very great difficulty. In the present instance it is desirable to learn, so far as possible, not merely the difference in composition between the fresh and altered rock, but, what is of greater importance, the proportional loss or gain of the various constituent elements, as well as the change in their method of combination. The problem is rendered one of very great difficulty from the fact that we do not know with any degree of precision just what may have been the actual processes involved. From the manner in which the decomposed rock conducts itself toward solvents and from a study of the percentage figures in the table, it is, however, at once evident that hydration is an important factor, and that a very appreciable amount of material has been carried away in solution; also, that of the material remaining a considerable amount exists in combinations quite different from those in the fresh rock. These are facts that have long been recognized.

In seeking to determine what proportion of material has actually become lost, it is necessary to select some one of the constituents which shall serve as a means of comparison. It is self-evident that the constituent thus selected should be the one which suffers least change, or a known change, during the process of decomposition.

It is a commonly accepted fact that of all those constituents occurring in considerable quantities in silicious, crystalline rocks, the alumina is the most refractory and least liable to be carried away through the solvent action of water. Hence Justus Roth † and others have not infrequently selected this as the constant factor, and by recalculating the results of analyses on the basis that all the alumina of the original rock

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* The petrology of the clastic rocks must evidently begin with a study of the products of rock degeneration.

† Allegemeine u. Chemische Geologie, vol. 3, 1893.

was retained by the residual clay, have arrived at very interesting, though not absolutely accurate results; this for the reason that alumina is not wholly insoluble in meteoric waters. Indeed, in many instances which might be cited, the iron oxides are apparently more refractory than the alumina, as will be noted later. By a comparison of the analyses of fresh and decomposed rock it is, however, evident that in this particular case the alumina has remained most nearly constant. Recalculating, then, the matter in columns 1 and 2 on the basis of 100 and considering the alumina as a constant factor, we get the results given in columns 8, 9 and 10, the last representing, so far as it can be obtained by this method, the actual percentage loss of materials attending the breaking down or degeneration, as we may well call it.*

Calculated Loss of Material.

	8	9	10	11	12
Constituents.	Recalculated on basis of 100.		Percentage loss for entire rock.	Percentage of each constituent saved.	Percentage of each constituent lost.
	Fresh diabase.	Decomposed diabase.			
SiO_2	47.01	44.51	8.48	81.97	18.03
Al_2O_3	20.11	23.24	0.00	100.00	0.00
Fe_2O_3	3.63	12.71	2.42	81.90	18.10
FeO	8.83				
CaO	7.06	6.04	1.83	74.11	25.89
MgO	3.15	2.85	0.68	78.30	21.70
MnO	0.77	0.52	0.32	58.43	41.57
K_2O	2.14	1.75	0.62	70.85	29.15
Na_2O	3.91	3.94	0.50	87.17	12.83
P_2O_5	0.68	0.70	0.08	88.61	11.39
Ign	2.71	3.74	0.53†	100.00‡	0.00
	100.00	100.00	14.93%		

From these figures it appears that there has been a loss of some 14.93 per cent of all constituents. The increase in water, as indicated by the ignition, is a natural consequence of hydration and the presence of a

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*Since the process is in part physical, the term decomposition is hardly applicable here. A comprehensive term, noncommittal as to which force is operative, is needed. Rather than coin a new word, and as preferable to "breaking down," I have used the term degeneration.

†Gain.

‡The calculation gives 119.49 per cent, showing a gain in volatile matter, as is to be expected.

small amount of organic matter. This increase, it should be stated, is greater than may at first be apparent, for the reason that the fresh rock contains a considerable amount of secondary calcite, which is quite lacking in the residual sand. A large part of the ignition in columns 1 and 8 is therefore to be accredited to carbonic acid and not to water of hydration.

We have as yet, however, fallen far short of the desired results, and in columns 11 and 12 I have attempted to show the actual percentage amounts of the original constituents that have been saved or lost during this process of decomposition. In these calculations, as before, the alumina is considered a constant factor. The method of calculation is not new, or at least is so only in its mode of application. A similar method was employed by Dr R. A. L. Penrose in considering the origin of manganese deposits through the decomposition of manganiferous limestones,* though in his case the silica was considered the constant factor.†

From the figures thus obtained it appears that of all the essential constituents the lime and potash salts have suffered the most, though the iron oxides have also been carried away in amounts equaling 18.10 per cent of their original percentages. Magnesia has also proven very susceptible to the solvent action, disappearing to the amount of 21.70 per cent; and, lastly, silica to the amount of 18.03 per cent. The small original amounts of manganese and phosphoric acid render the results obtained by these calculations as of doubtful value, since it is possible they may be due in part to errors of analysis.

In order to further test the method I have recalculated analyses of (1) fresh and highly weathered diabase from Venezuela, as given by G. Atwood,‡ and also (2) the granitic analyses given by myself in the publication already alluded to.§ In both cases the iron (Fe_2O_3) was found to be the most stable factor. The results thus obtained are given on the opposite page.

From these tables it appears that in the case of diabase the total loss equals 39.51 per cent, with an actual gain in volatile matter. Of the individual constituents, 83.23 per cent of the original lime; 61.37 per cent

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* Ann. Rep. Geol. Survey of Arkansas, vol. 1, 1890.

† The formulæ employed in the calculation is as follows:

$\frac{A}{B \times C} = X$; and $100 - X = Y$, in which $A =$ the percentage of any given constituent in the residual material; $B =$ the percentage of the same constituent in the fresh rock, and $C =$ the quotient obtained by dividing the alumina of the residue by that of the fresh rock (in this particular case 1.155), the final quotient being multiplied by 100. X then equals the percentage of the original constituent saved in the residue and Y the percentage of the same constituent lost.

‡ Quart. Jour. Geol. Soc. of London, vol. xxxv, 1879, part 2, p. 586.

§ In this paper, it will be remembered, the writer contented himself with calculating the results of analyses back to a water-free basis, whereby an "apparent loss" of only some 3 per cent of material was indicated as against 14.93 per cent by this method.

of the magnesia; 45.88 per cent of the potash; 95.37 per cent of the soda; 42.40 per cent of the silica, and 21.38 per cent of the alumina have disappeared. In the case of the granite, where the decomposition was much

Analyses of fresh and decomposed Diabase from Spanish Guiana, Venezuela.

Constituents.	Fresh.	Decomposed.	Percentage gain or loss for entire rock.	Percentage of each constituent saved.	Percentage of each constituent lost.
SiO_2	49.35	43.38	20.92	57.60	42.40
Al_2O_3	15.30	18.36	3.27	78.62	21.38
Fe_2O_3	......	20.39	0.00	100.00	0.00
FeO	12.28	....	....	....	....
CaO	9.60	2.37	8.05	16.17	83.23
MgO	7.38	3.45	5.12	30.63	61.37
K_2O	.85	0.59	0.33	54.12	45.88
Na_2O	1.98	0.14	1.82	4.63	95.37
Ign.	3.25	11.34	4.18*	228.62*	0.00
	100.00	100.00	39.51		

Analyses of fresh and disintegrated Granite from the District of Columbia.

Constituents.	Fresh granite.	Decomposed granite.	Percentage gain or loss for entire rock.	Percentage of each constituent saved.	Percentage of each constituent lost.
Silica (SiO_2)	69.61	65.84	10.50	85.11	14.89
Alumina (Al_2O_3)	14.39	15.26	0.46	96.77	3.23
Titanium oxide (TiO_2)	....	0.31	....	....	....
Ferric oxide (Fe_2O_3)	....	4.40	0.00	100.00	0.00
Ferrous oxide (FeO)	3.61	....	....	... .	....
Lime (CaO)	3.22	2.64	0.81	74.79	25.21
Magnesia (MgO)	2.45	2.65	0.036	98.51	1.49
Soda (Na_2O)	2.71	2.12	0.77	71.38	28.62
Potash (K_2O)	2.68	2.00	0.85	68.02	31.98
Phosphoric acid (P_2O_5)	0.10	0.06	0.04	60.00	40.00
Ignition	1.23	4.72	2.16*	349.62*	0.00
	100.00	100.00	13.466		

* Gain.

less, the total loss of materials amounts to but 13.46 per cent, with gains in volatile constituents as before. Of the individual constituents, 28.62 per cent of the original soda; 31.98 per cent of the potash; 25.21 per cent of the lime; 40 per cent of the phosphoric acid; 14.89 per cent of the silica, and 3.23 per cent of the alumina have disappeared.

It need scarcely be observed that these results cannot be considered absolutely satisfactory. The fact that it is found necessary to change our basis for calculation as occasion demands, from the alumina to the iron oxide, in order to avoid an actual and presumably impossible gain in certain constituents,* shows at once that the method is liable to serious error. Moreover, as in all such cases, any slight change in the figures of the analysis is exaggerated in those of the resulting calculations. I believe such errors to be, however, always on the side of too low estimates of the material lost, and in spite of the acknowledged inaccuracy, it seems to me to be one yielding very interesting and, when proper allowances are made, instructive results as well.

TIME LIMIT AND EXTENT OF DISINTEGRATION.

As was the case with the disintegrated rocks of the District of Columbia, we are enabled here also to fix a geological limit to the beginnings of disintegration. As above noted, the dike occurs in a region of extensive glaciation. This is so evident and well known as to need no confirmatory statement. That the disintegration and decay into which the rock has fallen is subsequent to the glaciation, and is not an isolated case of protection from erosion, as might at first be thought, is shown by the presence of glacial striæ still traceable over the surface of portions of the decomposed dike and the deposit of till overlying it, as shown in the plate. It is, of course, possible that decomposition had set in prior to the period of glaciation. That the process had not gone on extensively, however, is evident from the fact that the material was still sufficiently firm to receive the glacial markings. We are apparently safe in assuming that this disintegration and decay, or *degeneration*, as I have called the combined processes, and which extends to a depth of 30 feet, or perhaps 50 feet or more along joint plains, is mainly postglacial.† That the degeneration has here gone on more extensively than in other dikes of the vicinity is due, as the writer believes, to its coarse and somewhat granular structure,

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* The tables for the Venezuela diabase, when recalculated on an alumina constant basis, showed the total loss of all constituents to be 33.08 per cent, with an apparent gain of 3.35 per cent in iron oxides. This gain is doubtless due in part to a change in condition from FeO to Fe_2O_3. The granite analyses, similarly calculated, showed a total loss of 9.74 per cent, with an apparent gain of 1.15 Fe_2O_3 and 0.05 per cent MgO.

† This is the conclusion also reached by Crosby. Technological Quarterly, vol. iii, no. 3, August, 1890, p. 237.

and also to the character of the alteration which had gone on prior to and contemporaneous with degeneration.

I have often noted, both in eastern Massachusetts and elsewhere, that in cases where the mineral alteration had given rise to epidote and free quartz, as is the case in many of the diabasic dikes hereabouts, they resist decomposition even more successfully than do the granitic and other rocks by which they may be inclosed. Where, on the other hand, the alteration yielded mica, chloritic and zeolitic compounds, degeneration almost invariably ensues.

Relative Rapidity of Rock-weathering in high and low Latitudes.

An impression is still to some extent prevalent to the effect that rocks decompose more rapidly in warm and moist than in cold climates. This is shown in the writings of Kerr, Stubbs, Storer, Branner and others. While, owing to abundance of vegetation and other supposed favorable conditions, a more rapid decomposition may possibly be expected, such has not as yet been proven to actually take place, and indeed many facts tend to prove the impression quite erroneous. Lack of decomposition products in high latitudes is not infrequently due to glaciation or erosion by other means, as has been suggested by Pumpelly.*

Whitney,† Chamberlain and Salisbury ‡ have shown the presence of residual clays of all thickness up to 25 feet in the driftless area of Wisconsin, and Chamberlain § has described limited areas of strongly decomposed gneiss in the nonglacial areas of Greenland.

Moreover, we have no actual proof that the action of frost is on the whole protective, as is stated by Branner. || It must be remembered that frost penetrates to but a slight depth, and, while it undoubtedly puts a temporary stop to chemical action on the immediate surface, it remains yet to be shown that the mechanical disruption which there ensues is not as efficacious as would have been the chemical agencies alone had they been permitted to continue their work. Through bringing about a finely fissile or pulverulent structure, whereby a vastly greater amount of material becomes exposed, frost on and near the surface prepares the way for chemical action at a thousandfold more rapid rate than could otherwise have been possible.¶

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* Am. Jour. Sci., vol. xvii, 1879, p. 133.

† Rep. Geol. Survey of Wisconsin, 1861.

‡ Sixth Ann. Rep. U. S. Geol. Survey, 1884-'85.

§ Bull. Geol. Soc. Am., vol. 6, 1895, p. 218.

|| Ibid., vol. 7, 1896, p. 282.

¶ That a frigid climate is much more trying on stone exposed in the walls of a building is a fact apparently well established. Indeed, the action of frost and the constant expansion and contraction from natural temperature variations are among the most potent of agencies in promoting the disintegration of stones so used. See Stones for Building and Decoration, Wiley & Sons, New York.

If, further, as I have elsewhere at least suggested,* hydration is a most potent factor in rock disintegration, the process can go on uninterruptedly below the level of freezing.

The extremely energetic manner in which frost action may manifest itself under favorable conditions is well set forth in the following memoranda made by Dr L. Stejneger during his stay at the Commander islands in Bering sea. He says:

> "In September, 1882, I visited Tolstoi Mys, a precipitous cliff near the southeastern extremity of Bering island. At the foot of it I found large masses of rock and stone which had evidently fallen down during the year. Most of them were considerably more than six feet in diameter, and showed no trace of disintegration. The following spring, April, 1883, when I visited the place I found that the rocks had split up into innumerable fragments, cube-shaped, sharp-edged and of a very uniform size, about two inches. They had not yet fallen to pieces, the rocks still retaining their original shape.
>
> "I may remark, however, that the weather was still freezing when I was there. The winter was not one of great severity, and several thawing spells broke its continuity.
>
> "These cubic fragments did not seem to split up any further, for everywhere on the islands where the rock consisted of the coarse sandstone, as in this place, the talus consisted of these sharp-edged stones."

Professor H. P. Cushing has also remarked the extensive disintegration of the argillites at Glacier bay, Alaska. He says:

> "Disintegration takes place with amazing rapidity, as shown by the enormous piles of morainic matter furnished to the tributaries of Muir glacier, whose valleys are adjoined by mountains of argillite and by the massive talus heaps that are rapidly accumulating at the bases of other mountains, made up of the same material." †

This breaking down is largely physical and due to frost action, as described in the notes of Dr Stejneger above. In a private communication to the writer Professor Cushing further states that the diabase dikes of the region are fully as much decomposed as those of the Adirondacks, and that the boulders of eruptive rocks in the moraines are also far gone in decomposition.

In temperate regions we have further to consider the possible increased amounts of atmospheric gases brought down by snowfalls over those brought by rain. The snow flakes in falling so completely fill the air as to rob it of a larger proportion of the gases than would a corresponding amount of precipitation in the form of rain. Further, the snow in melting slowly away affords the water better facilities for soaking into the

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* Bull. Geol. Soc. Am., vol. 6, p. 331.

† Trans. New York Acad. of Sciences, vol. xv, 1895, p. 25.

ground than though it was poured down during the comparatively brief period of a shower. How far these agencies may go toward counterbalancing the effects of the continued higher temperatures of the tropics we have no means of judging.*

It is even questionable if decomposition has actually gone on to greater depths in regions covered by forests, as contended by Hartt,† than elsewhere. The accumulation of a large amount of organic matter is undoubtedly favorable to decomposition, but the growing vegetation constantly robs the atmosphere of carbonic acid and the soil beneath of moisture and other elements necessary for its growth, storing them away in the form of woody fiber or sending them off into the atmosphere once more. The amount of moisture that a full-grown tree evaporates daily through its leaves is simply enormous, and is often made conspicuously apparent by the dry knolls which may be seen surrounding isolated trees or groups of trees in swampy areas.‡

The apparent amount of decomposition in wooded areas may be greater, simply for the reason that the ground is protected thereby from the erosive action of running water.

It is my present belief that the opinion regarding the more rapid rate of degeneration in warm climates and forested areas is founded on no other basis than the visible accumulation of rock debris, and that this accumulation is rendered possible through the protective action of plant life, which is naturally more profuse in warm than in cold climates.

That, however, there may be a difference *in kind*, in the degeneration, in warm and cold climates, or at least in moist and dry climates, is possible and even probable. In cold and in dry climates subject to extremes of temperature, as in the arctic regions, or in the arid regions of lower latitudes, the degeneration is first almost wholly in the nature of disintegration, a process of disaggregation whereby the rock is resolved into, first, a gravel, and ultimately a sand composed of the isolated mineral particles which have suffered scarcely at all from decomposition. The writer has elsewhere referred to this form of degeneration as manifested in the desert regions of the Lower Californian peninsula.§ In warm, moist climates chemical decomposition may or may not keep pace with the disintegration, according to local conditions, so that the resultant material may be in the form of an arkose sand, as in the District of

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* There is an old saying among eastern farmers to the effect that a late spring snowstorm is as good as a dressing of manure. It undoubtedly arose from an appreciation by the farmers of the fact that the snow was more beneficial than rain, for the reasons above mentioned.

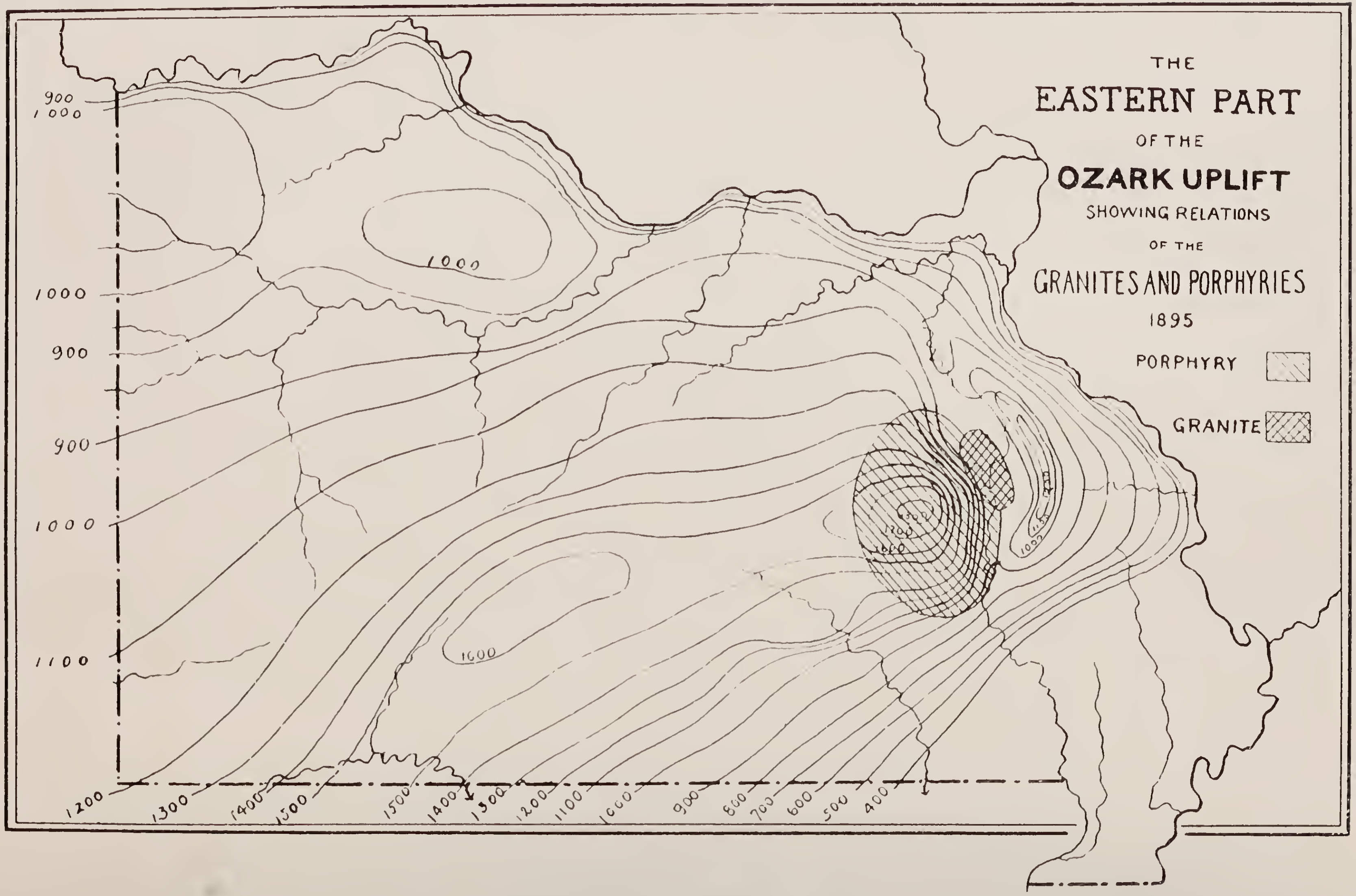
† Geology and Physical Geography of Brazil.

‡ It is stated that a grove of 500 full-grown healthy trees emit during every 12 hours of daylight 4,000 tons of moisture. (H. de Varigny: The Air and Life. Report Smithsonian Institution, 1893.)

§ Bull. Geol. Soc. Am., vol. 5, 1894, p. 499.

Columbia, or a residual clay, as in the more superficial portions of the saprolitic deposits to the southward. In certain cases, or among certain classes of rocks, the decomposition proceeds at so rapid a rate that there is scarcely any apparent preliminary disintegration. Local circumstances and character of rock masses being the same, we are, however, apparently safe in assuming that in warm and moist climates decomposition follows so closely upon disintegration as to form the more conspicuous feature of the phenomenon, while in dry regions, or those subject to energetic frost action, mechanical processes prevail and disintegration exceeds decomposition. I can but regard this point as one of considerable geological significance. The source of certain materials forming secondary rocks being known, it is possible that from their condition, as regards decomposition, we may be able to draw some conclusions as to existing climatic conditions at the time of their formation; or if not of climatic conditions, at least some idea as to relative rapidity of formation, an arkose indicating either that physical agencies due to climatic conditions prevailed, or else that the rapidity of disintegration, transportation and deposition was such that chemical agencies had little chance to get in their work.

These remarks are intended to be applicable mainly to silicious rocks.



EASTERN PART OF THE OZARK UPLIFT

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GEOGRAPHIC RELATIONS OF THE GRANITES AND PORPHYRIES IN THE EASTERN PART OF THE OZARKS

BY CHARLES ROLLIN KEYES

(Presented before the Society December 26, 1895)

CONTENTS

INTRODUCTORY.

The granitic rocks of Missouri are the only massive crystallines occurring between central Arkansas and lake Superior and between the Appalachians and the Rocky mountains. They are the most ancient rocks exposed in the central Mississippi basin. As irregular, discontinuous fields and isolated hills the crystalline masses are scattered over a district of more than 3,000 square miles, in the southeastern part of the state. They are all igneous in origin and pre-Cambrian in age.

Important as the region is as a mining district, and as much as has been done toward an inquiry into the nature of the mineral deposits, it is somewhat remarkable that so little attention has been paid to deciphering the stratigraphy of the region. Only very recently have the stratified rocks begun to receive serious attention, while until lately, when their consideration was taken up by Haworth * according to modern petrographical methods, hardly anything was known regarding the crystalline rocks beyond their mere existence.

General geological Features of the Region.

The crystalline area of southeastern Missouri is a highland district, and constitutes what has been recently † termed the Saint Francois mountain group. It forms in this state the eastern portion of the Ozark uplift and is a part of the granitic foundation which has been exposed through profound erosion. Around the nucleus of ancient crystallines the strata of the subsequently deposited formations are grouped in concentric belts of greater or less breadth. The crystalline nucleus is composed almost entirely of granites, porphyries, and diabases.

In many places an imperfect bedding is often noticeable in the porphyries and granites, which fact formerly gave rise to the belief that these rocks were sediments which had undergone metamorphism to such an extent that they were now in the last stages of the process. It has been recently demonstrated that the apparent lines of sedimentation are in reality pseudo-stratification planes, and that they have been developed in a way that is widespread among rocks which have cooled from molten magmas.

The continuity of the massive rocks is interrupted by numerous lines of fracture. Most of these are merely joint-planes, many are slight fault lines, while still others have the walls spread apart, the space being filled with basic material forming dikes, which are sometimes of considerable breadth.

The joint-planes form several different series. Great uniformity in direction is exhibited by those belonging to the most prominent set. Slight deviations occur, but the general trend is north 60° east. The second series makes angles of 80 and 100 degrees with the more prominent one.

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* Missouri Geol. Survey, vol. viii, 1895, pp. 80–222.

† Missouri Geol. Survey, Iron Mountain Sheet, 1894, p. 4.

Faulting is commonly quite unimportant, the throw being usually not more than a few feet. Some notable exceptions, however, are known. The position and extent of the dislocations are more clearly defined in the stratified rocks than in the crystallines.

Dikes of basic rock occur rather abundantly. They vary from a few inches to 50 yards or more in width and cut the granites and porphyries alike. Nowhere have they been observed to penetrate the overlying sedimentaries. Their number and wide distribution, the great weight and black color of the rock composing them, and their peculiarities in weathering cause them to attract wide attention.

The crystalline masses of the region are all older than the sedimentary strata which everywhere rest unconformably upon these rocks. A long period of erosion is represented by this unconformity. Abundant evidence shows that when the sedimentary rocks were laid down the diversity of surface relief was even greater than at the present time. To this very marked irregularity in the pre-Cambrian surface may be ascribed many anomalous stratigraphic features which are met with throughout the region.

The sedimentaries are represented by an extensive succession of magnesian limestones with intercalated sandstones. . Almost always the latter immediately cover the pre-Cambrian elevations; they also occupy positions between the calcareous beds.

The stratified rocks dip away in all directions from the central crystalline area. Younger and younger strata successively form the surface rocks as the distance increases from the porphyry hills. The Paleozoic is well represented from the Cambrian to the Carboniferous. From Iron mountain to the nearest point on the Mississippi river, a distance of 30 miles in a northeasterly direction, the entire sequence from the basal granite through the Cambrian, Ordovician, Silurian, Devonian, and Carboniferous to the Coal Measures, is passed over.

THE CRYSTALLINE ROCKS.

TYPES REPRESENTED.

During the past few years the crystalline rocks of Missouri have been carefully mapped, and the geographic distribution of the principal varieties determined. It is due, however, to the petrographical investigations of Haworth * that the various mineralogical and structural types have been made out.

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* Loc. cit.

Tabulated, they are as follows:

Granites.	Granular	Granite (proper).
		Granitite.
		Hornblende-granite.
	Porphyritic	Granite-porphyry—phenocrysts feldspathic.
		Granite-porphyry—phenocrysts quartzose.
	Granophyric	Granophyre.
Porphyries	Porphyrite.	
	Porphyry	Microgranite.
		Granophyre.
		Felsophyre.
		Vitrophyre.
Dike rocks	Ophitic	Diabase.
		Olivine-diabase.
	Porphyrite	Diabase porphyrite.
		Quartz-diabase-porphyrite.
	Glassy	Diabase-porphyrite.
		Melaphyre.

The subordinate types require no special elaboration in the present connection. All the basic rocks, with a few possible exceptions, occur in narrow dikes and may be also neglected. Only the two leading facies of the acid rocks demand particular attention.

LITHOLOGICAL CHARACTERS OF THE GRANITES.

The granites are rather coarse grained rocks, of a reddish to grayish color. They are almost wholly mixtures of orthoclase and quartz, with a little biotite or hornblende as the third essential component. The plagioclase feldspars occur sparingly; the accessories, magnetite, zircon and apatite, are present only in minute crystals and are not abundant. One of the most striking features in the mineralogical constitution of these rocks is their poverty in the ferromagnesian silicates.

As a rule the texture approaches the porphyritic and the rock passes into a true granite-porphyry. Phenocrysts an inch or more in length are not infrequent in many places. On the other hand the rock becomes fine grained, graduating finally into typical porphyry. In the porphyritic facies of the granite the feldspars make up the greater part of the groundmass. The individuals have so interfered with one another in their growth that they have produced a hypidiomorphic, granular mass in which quartz grains occur abundantly. Occasionally the latter have some of their crystallographic faces preserved. In acidity the rocks are slightly above the average of similar masses from other parts of the world, often reaching 77 per cent of silica (SiO_2).

LITHOLOGY OF THE PORPHYRIES.

The fine grained acid rocks are generally of a reddish color; there is, however, a wide range from light pink to a dull, dark gray or purple. In texture there is considerable variation. The groundmass is dense and very fine grained. It assumes all gradations, from a coarse microgranite to a fine divitrified glass. Through the groundmass are scattered abundantly large individuals of quartz and feldspar, the phenocrysts. The fine grained, compact character of the rock enables it to resist degradational influences in a remarkable way, as is shown by the fragments loosened in jointing, which preserve sharply all their irregularities long after the granite boulders have become perfectly rounded or entirely decayed. The rugged topographic forms also clearly indicate the same properties of withstanding weathering influences. The fracture of the porphyry is splintery or subvitreous.

What has already been said regarding the mineralogical composition of the granite applies also to the porphyry. The chief constituents are the feldspar and quartz, but the difference in the structure of the rock results in very different relationships. The accessories, zircon, magnetite and apatite, are found scattered through the groundmass. The ferromagnesian ingredients are not, as a usual thing, well developed. The feldspars are the same as those of the granite and comprise the three varieties, orthoclase, microcline and albite. They range from grains of microscopic dimensions in the groundmass to large phenocrysts nearly an inch in length. The porphyritic crystals of quartz are frequently rounded, with the characteristic embayments due to partial remelting before the original solidification of the mass.

The most striking differences between the granite and porphyry are shown when thin sections of the two rocks are examined under the microscope. The fine grained matrix in which are imbedded the larger crystals at once characterizes the latter type. The groundmass varies considerably, from the typical micrograuitic structure to an almost glassy one, which, however, is usually so thoroughly devitrified that its original character can hardly be recognized. The various phases which are especially noticeable are the micrograuitic, granophyric, micropegmatitic, felsophyric, vitrophyric and spherulitic. A particularly interesting facies is the trachytic, in which the minute crystals of lath-shaped feldspars are arranged the same as in diabase. The phenocrysts are mainly quartz, though feldspars are not of infrequent occurrence.

CONSANQUINITY OF THE ACID ROCKS.

Nowhere does a sharp line of demarkation exist between the porphyry and the granite. When closely associated the two kinds of rocks merge into each other gradually. The transition zone varies in different places from a dozen to a hundred or more yards in width. It appears to afford good evidence that in general the two rock masses represent not necessarily numberless separate eruptions, as once believed, but for all practical purposes a single one or comparatively few, with special differentiation in the different parts.

As already stated, the chemical composition of the granite and the porphyry is the same. Their mineralogical constitution is likewise essentially identical. The chief difference discernible between them is merely in the size, arrangement and relations of the components. Since the structural characters of igneous rocks are dependent largely if not entirely upon the accidental physical conditions under which the molten magmas have cooled and solidified, it is of prime importance in the consideration of the relations of different phases of the same body of rock to take into account the fundamental principles involved in the production of the several facies. It is a well known fact that under ordinary circumstances the texture of a rock mass of igneous origin is glassy or very fine grained at the surface, and as the distance from its exposed face increases the grain becomes coarser. Granite is commonly regarded as a deep seated rock, one which has solidified very slowly and under great pressure. Porphyry is formed where the pressure has not been so enormous and where the cooling has been retarded less. All the stages may exist in the same mass, but in the very old rocks devitrification has taken place in the glassy portions, and other secondary changes have usually greatly obscured or totally obliterated the original features. Moreover, degradation has often acted vigorously and erosion has removed much of the original surface of the rocks.

In the district under consideration just such conditions as those described appear to have prevailed. It has been observed that, with a few exceptions, wherever the granite and porphyry occur together the former occupies the lower levels. Within the larger granite areas, wherever high, steep sided hills exist, the coarse grained rock graduates upward into fine grained varieties and finally into the typical aphanitic porphyry which forms a protecting cap to the elevation. These gradations upward of the granite into porphyry are especially well shown in the case of certain isolated hills, and probably it would be found equally true in most cases if proper means of observation were afforded. The principal granite masses appear clearly to be areas in which the superior fine grained facies have been removed through erosion. The physiographic features of the region point to the same conclusion, as will be hereafter noted.

ORIGIN OF THE MASSIVE CRYSTALLINES AND THEIR PRESENT CONFIGURATION.

SUMMARY OF OPINION.

Since the time when King* made his first "Remarks on the Geology of the State of Missouri" there has been considerable difference of opinion as to the true character of the acid crystallines, but in all this half century until very recently little has been done beyond making general observations regarding the origin. More has been said, however, regarding the old configuration of the region.

Swallow† said nothing about the crystallines after making a general allusion to their igneous nature and giving a brief lithological description. Shumard ‡ likewise only briefly alluded to these rocks in his report on Sainte Genevieve county.

The view Pumpelly § took was that the porphyry region and the Ozarks generally had been above the sealevel from a very early period. "The higher portion of the elevation does not seem to have been submerged since before the Upper Silurian period, while broad areas in the flanks of the range have apparently been dry land since the Carboniferous."

In Broadhead's account || of Madison county the massive crystallines are regarded as metamorphosed sediments which have been broken through by dikes of quartz, greenstone, dolerite and specular iron ore. In subsequent allusion to the subject the view presented lately ¶ is the reiterated statement that the crystalline peaks have remained above the sealevel since early Cambrian times.

Winslow** follows closely the views previously expressed by Pumpelly and by Broadhead that the crystallines have been subjected to weathering agencies since Archean times.

RECENT INVESTIGATIONS.

During the past few years the massive crystallines of the region have been the subject of special inquiry by Haworth,†† who has studied with the microscope the rocks from nearly all parts of the area. He has shown beyond all doubt that they are all igneous in origin and not highly meta-

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* Proc. Amer. Assoc. Adv. Science, vol. v, 1851, pp. 182–200.
† Geol. Survey of Missouri, 1st and 2d Ann. Reports, 1855, pp. 134–135.
‡ Geol Survey of Missouri, 1855–'71, 1873, p. 300.
§ Geol. Survey of Missouri, Iron Ores and Coal Fields, 1873, p. 8.
|| Geol. Survey of Missouri, vol. i, 1874, p. 348.
¶ American Geologist, vol. xiv, 1895, p. 383.
** Missouri Geol. Survey, Iron Mountain Sheet, 1894, p. 6.
†† Missouri Geol. Survey, Bull. 5, 1891, pp. 5–42.

morphosed sediments, as was once supposed. The most important observation is that in general the porphyries and granites were formed about the same time, and that consequently neither can be regarded as younger than the other.[*] Numerous cases are noted in which the complete transition from one facies to the other takes place within a very short distance. The conclusion is also reached that there are—

> "Good reasons for believing that many of the prominent porphyry hills are the results of individual outbursts," and that they "are formed of the lava which reached the surface and formed variously shaped volcanic mountains or hills and monticules, the lava of which would connect directly with the deeper seated material."[†]

Still more recently[‡] the problem of the present distribution and relations of the granites and porphyries have been considered anew, with special stress placed upon the physiographic evidences, and very suggestive results have been obtained.

General areal Distribution.

Stripped of its various thin patches of sedimentaries the main body of massive crystallines forms a broadly oval area about 50 miles long. Of this the granite occupies about one-fourth, but is confined almost exclusively to a single large mass in the northeastern part of the district. Beyond the limits of the chief porphyry area there are numerous mounds which rise out of the general limestone field. Outside of the main granite body there are also other localities where the coarse grained rock occurs, but the areas are small and rarely exceed a superficial extent of one square mile. As incidentally observed by Haworth and others, the granites as a rule occupy the lower ground when occurring near the porphyries, but the full significance of the fact seems to have escaped notice. Many of the peculiarities and irregularities in the present surface distribution are without doubt due to pre-Cambrian erosion, but recent erosive agencies have also modified extensively the effects produced during the more ancient cycles. In this connection, however, it is unnecessary to go beyond the main features relative to the geographic distribution of the principal masses.

Physiography of the Region.

MAIN CHARACTERISTICS.

The crystalline district of Missouri forms the eastern end of the crest of the Ozark uplift. It is a semialpine region, with prominent solitary

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[*] Missouri Geol. Survey, vol. viii, 1895, p. 218.

[†] Ibid., p. 219.

[‡] Missouri Geol. Survey, vol. ix, 1895, pt. iv.

peaks irregularly distributed rather than arrayed in ranges and ridges. The extremes of altitude are about 500 to 1,800 feet above tide level. The general elevation is in the neighborhood of 1,000 feet.

In the extreme eastern part of the crystalline district two principal types of topography are represented. One is made up of a very much broken or hilly region; the other is a broad plain, with rather rough, rolling surface. The first of these comprises the porphyry peaks which constitute a portion of the Saint Francois mountains, a group of more or less rugged hills which stretch away to the southwestward in an interminable succession of tumuli of nearly uniform height. There is no systematic arrangement discernible in these prominent surface features. Although indistinctly defined ridges may be sometimes made out, the rule is isolated mounds, large and small, rising irregularly behind one another. The landscape presents a number of the more important ones, all of nearly the same height, equally distant from one another, and surrounded by smaller hills. The peaks stand out in marked contrast above the surrounding valleys. Owing to the resistant character of the pricipal massive rocks, disintegration goes on much more slowly than with the sedimentaries. Hence the slopes of the porphyry hills are much steeper than any of the others. Along the streams where the waters impinge against the banks perpendicular walls are often formed, which rise to a height of 200 or 300 feet before the surface of the mounds assumes a normal slant.

Being beyond the limits of glaciation, the inequalities of the indurated rock surface have not been softened or modified by accumulations of extralimital detritus, and ice debris has in no way altered or obscured the topographic expression.

The present topographic features are the product of two cycles of erosion. The evidence of the earlier of these is now nearly obliterated by the vigorous action which has characterized the later.

The leading features of the area indicate with great clearness both the comparative resistance of the various rocks and the geological structure of the region. The stratified rocks dip rapidly to the north, east and south, away from the central granite mass. All the rocks are hard and resistant, but, as compared with one another, marked differences are found in this respect. With the vigorous erosion which has lately been renewed, the effects of the varying hardness of the several rock masses greatly intensifies the contrasts of the relief. Hence the areas occupied by porphyry, granite, cherty limestone, ordinary limerock and sandstone all differ in their topographic physiognomy, but the several types may be readily grouped into two principal phases, of which one forms an upland and the other a lowland plain. The first is the deeply incised constructional surface—the Tertiary peneplain—and the second is a moderately dissected plain lying at a somewhat lower level.

TERTIARY PENEPLAIN.

The most notable physiographic feature of Missouri is the great Tertiary peneplain which forms the general surface of the Ozark uplift. All of the present topographic expression of the southern part of the State, varied as it is, is but the effect of erosion in the effort to again reduce the region to baselevel. In no part of the uplift, unless it be in the Saint Francois district, does any portion of the pre-Tertiary surface project above the broad constructional plain, and even here the nearly uniform height to which the numberless peaks rise would indicate that they also were practically obliterated in Tertiary time, at least as prominent surface features. At the extreme end of the uplift, where the crest begins to pitch to the eastward and within the boundaries of what is called the Mine la Motte district, the remnants of the peneplain which constitutes the upland are found only in the southern or southwestern part and in the northeastern portion. The latter is separated from the southwestern upland by a broad expanse of lowland. The areas of upland possess rugged relief, particularly in the southwest. The northeastern district forms a part of the drainage divide which separates the waters which flow directly into the Mississippi river from those which flow in the opposite direction into the Saint Francois. The foundations of the upland are the hardest rocks—in the southwest the porphyries and in the other parts cherty limestones.

The region occupied by the former is deeply cut by the streams, the principal one being the Saint Francois river, which traverses the area in a general north-to-south direction. The tributaries are small, numerous, torrential. The valleys are contracted and steep-sided, and the flood plains very narrow. Above them the porphyry hills rise in high, regularly rounded mounds with almost precipitous slopes.

The persistent strength of the other portion of the upland surface in the northeast is a hard, very cherty limestone which overlies softer, less silicious beds of limerock. Beyond the limits of the district the upland is continuous, and the portions appearing within the boundaries are long lobes or extensions which project out from main body. These ridge-like elevations terminate abruptly in steep slopes which form sections of a rather pronounced escarpment of tortuous course, but having a general trend of northwest and southeast. The sides of the declivity present sharply incised or crenulated outlines. The hills formed are thickly covered by the hard cherty fragments which obscure or totally hide the strata underlying. Several prominent chert-covered hills which occupy isolated positions beyond the boundaries of the escarpment appear to be remnants of the steep slope at a time when it extended out into the lowland much further than at present. These solitary mounds often present a striking contrast to the surrounding country and form conspicuous features of the local landscape.

FARMINGTON LOWLAND PLAIN.

The median plain which occupies a large portion of the Mine la Motte country is a part of a broad zone that extends over a much more extensive area. It is limited on the east by the irregular cherty escarpment of the upland forming the divide between the Mississippi and Saint Francois rivers. On the west the porphyry hills interrupt its continuity. The general elevation of the plain is about 1,000 feet above mean tide. This level is 700 to 800 feet below the horizon of the great peneplain (figure 1).

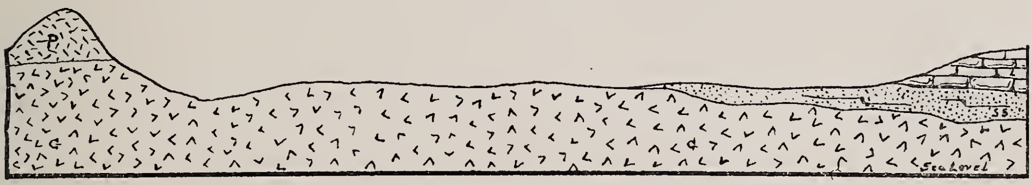

FIGURE I.—*Geological Cross-section of Farmington lowland Plain.*

The rocks of the Farmington plain are soft, or at least succumb much more easily to meteorologic influences than do the fine grained crystallines and the chert-bearing dolomites. The principal features are the outcome of rather vigorous erosive action upon limestones and sandstones and the general surface is rolling. Wherever the calcareous beds predominate, the topographic outlines are rounded and greatly softened; where sandstones occur the relief is bolder. In the lowland the river valleys have a tendency toward a broad, open type, in contradistinction to those of the upland, where narrow, contracted gorges prevail. The extent of the plain, however, is not confined to the areas of limestone and sandstone, but, with some modifications, covers also the granites. The latter, disintegrating much more readily than the porphyries, leave the areas occupied by the fine grained rocks standing far above them. The surface relief of the granite district is noticeably more rugged than that of the sedimentary areas, but the comparative resistances of the two kinds of rock are not so diverse but that the areas occupied by them may all be grouped together.

The lowland is manifestly a plain of denudation. It is the product of a former cycle whose work was interrupted before completion. In point of time this cycle was a later one than that represented by the Tertiary peneplain and immediately preceded the present one. The effects of the present cycle of erosion are well shown in the sharply cut trenches in the plain, where erosion has recently been accelerated with vigor.

Relations of principal Types of acid Rocks to physiographic Provinces.

Recently topographic maps have been made of a portion of the region on a scale of one inch to the mile and with a contour interval of 20 feet. These sheets have afforded means of accurate comparison of different parts of the district which were previously not available. In the four occupied by the Farmington, Mine la Motte, Iron Mountain and Bonne Terre districts, two marked physiographic provinces have been distinguished, as already stated. There is a highland plain and a lowland plain. The great granite mass of the region lies entirely within the lowland plain. To the eastward it is covered by the limestone, which forms the drainage divide between the Saint Francois and Mississippi river systems; but beyond the ridge the granite again appears in some of the stream beds, as at Jonca (see plate 17).

From the relationship established between the large granite area and the lowland plain of denudation, the inference is that at this point in the Ozark uplift the surface facies of the granitic mass has been removed through erosion, in part perhaps in pre-Cambrian times, but largely at a very recent period. The fact that the surface facies has been actually eroded is shown by several high, isolated hills which rise out of the granite area. Some of these, as Knob Lick, for instance, are still capped by porphyry. They clearly indicate that from the surrounding area granite to a depth of over 400 feet has been removed in addition to the surface shell of porphyry.

It is a noteworthy fact that the large granite area is at the extreme eastern end of the Ozark crest. Not only are the three slopes fully exposed to erosive agencies, but proximity to the Mississippi river brings the extremes of altitude so closely together that the general erosion of the region is at a maximum at this point. Attention has been lately called to the apparently modern date of the Ozark uprising and the very recent acceleration of its growth, as clearly shown in certain physiographic features. The place of most pronounced elevation seems also to be in the Saint Francois district. This and the unusually favorable conditions for rapid erosion have been the direct cause of the removal of an amount of material greater than in any other part of the uplift and the exposure of rocks more ancient than at any other point. Three thousand feet would probably be a very conservative estimate of the thickness of the strata, most of which remained as a covering over the crystalline hills until a very recent period. The column embraces a good representation of the entire Paleozoic above the middle Cambrian.

Age of the massive Crystallines.

While not wholly pertinent to the theme under consideration, it may not be entirely out of place to touch briefly upon the question of the geological age of the granitic rocks. In the preceding pages it may have been noticed that all specific allusions to their antiquity have been carefully avoided. Nothing more than the general statement of their pre-Cambrian origin has been offered. The reason is this: there is now a considerable element of doubt that their geological age is really what it has been generally assumed to be.

All who have had occasion to discuss the granites and porphyries have agreed in assigning them to the Archean. A single possible exception is Van Hise,*, who incidentally states that the granites may be of the same age as the clastics containing or associated with the ore beds of Pilot Knob and neighboring mountains. Haworth† may also have had a little doubt as to the correctness of the references of the granite to the Archean when he states:

> "It is quite remarkable that this comparatively large Archean area should differ so widely from the ordinary Archean rocks of America. Instead of being composed principally of great masses of gneiss and schist, not a single instance of either of these has been found, but in their stead are granites, porphyries, and porphyrites."

The absence of gneissic and schistose rocks in the massive crystalline area is a noteworthy fact. It is particularly suggestive in the light of the discovery in a deep-well boring near Kansas City of real evidences of squeezed rocks. The hole, which was made by a diamond drill, reaches a depth of nearly 2,500 feet. The core at the bottom is 1⅞ inches in diameter. The last 30 feet are reported to be in the rock, which examination shows to be a black mica-schist, the cleavage planes of which have a dip of 35 degrees. If the natural inferences are correct, the entire Paleozoic sequence from the base of the Upper Coal Measures has been passed through in a vertical distance of less than half a mile; the schistose floor, upon which rests the unaltered sedimentaries, has been reached in Missouri, and Archean rocks are present which are not unlike the more typical areas in other parts of the American continent. This being the

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* U. S Geol. Survey, Bull. 86, 1895, p. 504.

† Communication.

case, the normal and unchanged granitic rocks of the Saint Francois region probably do not belong to the Archean at all, but to that recently established system which represents the enormous interval of time between the formation of the truly Azoic rocks and deposition of the lowest Cambrian.

SUMMARY.

Recapitulating briefly, it may be stated that—

1. The granites and porphyries are very closely related genetically, and are to be regarded as facies of the same magma.

2. Whatever may have been their origin, whether from a few or many points of extravasation, the present relations of the two are that the porphyry is an upper and surface facies of the granite. The thickness of the former is variable, having been originally unequally developed in different places and subsequently modified by both ancient and recent erosion.

3. The present geographic distribution of the granites and porphyries is the outcome of very recent changes in the topographic configuration of the region, and is not of very ancient origin, as has been usually considered to be true.

4. The existing areal relations of the principal masses of the acid rocks may be traced directly to the systematic and widespread effects of recent orogenic action upon the physiography.

5. An element of uncertainty regarding the geological age of the massive crystalline rocks now prevails, and the determination of their exact age may perhaps always remain an unsolved problem.

6. The basal complex of Archean schists exists in Missouri within a very moderate distance beneath the highest Paleozoics. It differs widely in lithological characters from the crystallines of the state, which have been usually referred to that age, but clearly approaches the more typical Archean rocks of other districts.

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PLAINS OF MARINE AND SUBAERIAL DENUDATION

BY W. M. DAVIS

(Read before the Society December 27, 1895)

CONTENTS

INTRODUCTION.

Geologists today may be divided into two schools regarding the origin of regions of comparatively smooth surface from which a large volume of overlying rocks have been removed. These regions occur under two conditions: First, as buried "oldlands" on which an unconformable cover of later formations has been deposited, the oldlands being now more or less locally revealed by the dissection or stripping of the cover; second, as uplands or plateaus whose once even surface is now more or less roughened by the erosion of valleys.

The older school, now represented chiefly by English geologists, follows the theory of Ramsay, and regards these even oldlands as plains of marine denudation. The newer school, represented chiefly by American geologists, but also by a number of continental European geologists, may be said to follow Powell, who first emphatically called attention to the possibility of producing plains by long continued subaerial denudation. The present review of the question first cites a number of extracts from various representatives of the two schools, and then seeks for a test by which the rival conclusions may be distinguished, the test being developed from a study of the natural history of rivers.

THE ENGLISH SCHOOL.

Ramsay is believed to have been the first advocate of marine erosion as an agency for the production of broad plains of denudation. In describing the action of the sea on the land he wrote:

> "The line of greatest waste on any coast is the average level of the breakers. The effect of such waste is obviously to wear back the coast, the line of denudation being a level corresponding to the average height of the sea. Taking *unlimited* time into account, we can conceive that any extent of land might be so destroyed, for though shingle beaches and other coast formations will apparently for almost any ordinary length of time protect the country from the further encroachments of the sea, yet the protections to such beaches being at last themselves worn away, the beaches are in the course of time destroyed, and so, unless checked by elevation, the waste being carried on forever, a whole country might gradually disappear.
>
> "If to this be added an *exceedingly slow depression* of the land and sea bottom, the wasting process would be materially assisted by this depression, bringing the land more uniformly within the reach of the sea, and enabling the latter more rapidly to overcome obstacles to further encroachments, created by itself in the shape of beaches. By further gradually increasing the depth of the surrounding water, ample space would also be afforded for the outspreading of the denuded matter. To such combined forces, namely, the *shaving away* of coasts by the sea, and the spreading abroad of the material thus obtained, the great *plain* of shallow soundings which generally surrounds our islands is in all probability attributable."*

At this early date Ramsay attributed not only the plains themselves, but also the valleys which now interrupt ancient and uplifted plains of denudation, in greatest part to marine action, and allowed but little effect to subaerial denudation. On this topic he said:

> "The power of running water has also considerably modified the surface, but the part it has played is trifling compared with the effects that have sometimes been attributed to its agency. . . . In the larger valleys, where the streams are sluggish, instead of assisting in further excavations, the general tendency is often rather to fill up the hollow with alluvial accumulations, and so help to smooth the original irregularities of the surface." †

Thirty years later Ramsay ascribed greater results to subaerial agents. Referring to the generally even sky-line of South Wales, he wrote:

> "The inclined line that touches the hilltops must have represented a great plain of marine denudation. Atmospheric degradation, aided by sea waves on the cliffs by the shore, are the only powers I know of that can denude a country so as to

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* Denudation of South Wales. Mem. Geol. Surv. Great Britain, vol. 1, 1846, p. 327.

† Ibid., pp. 332, 333.

shave it across and make a plain surface either horizontal or gently inclined. If a country be sinking very gradually and the rate of waste by all causes be proportionate to the rate of sinking, this will greatly assist in the production of the phenomena we are now considering."

When raised out of the water—

> "The streams made by its drainage immediately began to scoop out valleys, and, though some inequalities of contour forming mere bays may have been begun by marine denudation during emergence, yet in the main I believe that the inequalities below the [level of the plain] have been made by the influence of rain and running water." *

Greenwood, an early advocate of the efficacy of "rain and rivers," (1857), directed his arguments against the prevailing belief of the time that valleys were carved by marine currents, but does not seem to have considered the possibility of producing plains by the long continued weathering and washing of the land.

The important paper by Jukes, on the "Formation of . . . river valleys in the south of Ireland," † still finds many followers among English geologists. Like Ramsay, Jukes assumed an uplifted plain of marine denudation on which the rivers of today began their erosive work (page 399), but he did not specify slow depression during the marine denudation.

Lyell said little on the problem before us. His "Principles" do not discuss plains of denudation. His "Elements of Geology" ‡ allow only small valleys to stream work, and ascribe the larger valleys "to other causes besides the mere excavating power of rivers" (page 70). It is said that "denudation has had a leveling influence on some countries of shattered and disturbed strata" (page 71). Again, "in the same manner as a mountain mass may, in the course of ages, be formed by sedimentary deposition, layer after layer, so masses equally voluminous may in time waste away by inches; as, for example, if beds of incoherent materials are raised slowly in an open sea where a strong current prevails" (page 70). The problem of subaerial denudation here discussed was not then formulated.

The writings of Sir A. Geikie offer several interesting quotations. When describing the general uniformity of the sky-line over the Scotch Highlands in the first edition (1865) of the "Scenery of Scotland," he writes:

> "In other words, these mountain tops are parts of a great undulating plain or table-land of marine denudation. . . . The marine denudation probably went

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* Phys. Geol. and Geogr. Great Britain, 5th ed., 1878, pp. 497, 498.

† Quart. Journ. Geol. Soc., vol. xviii, 1862, pp. 378–403.

‡ 6th edition, 1868.

> on during many oscillations of level, and the general result would hence be the production of a great table-land, some parts rising gently to a height of many hundred feet above other portions, yet the whole wearing that general tameness and uniformity of surface characteristic of a table-land where there are neither any conspicuous hills towering sharply above the average level nor any valleys sinking abruptly below it. . . . The valleys which now intersect it . . . have probably been dug out of it by the agencies of denudation. If therefore it were possible to replace the rock which has been removed in the excavation of these hollows the Highlands would be turned into a wide undulating table-land, sloping up here and there into long central heights and stretching out between them league after league with a tolerable uniformity of level. And in this rolling plain we should find a restoration of a very ancient sea" (pages 106–108).

On earlier pages, subaerial agents are described as producing valleys and cliffs, while the sea, aided by the atmosphere, produces a plain of marine denudation.

An essay "On modern denudation"* by the same author recognizes that plains of denudation are reduced mainly by subaërial forces, but concludes that "undoubtedly the last touches in the long processes of sculpturing were given by waves and currents, and the surface of the plain corresponds with the lower limit of the action of these forces" (page 186).

In the second edition (1887) of this delightful book on the Scenery of Scotland, argument is still directed against the prejudice that mountains are due to local upheaval; in a word, against the prepossession that mountainous districts like the Scotch Highlands are constructional forms not significantly modified by denudation; but greater value is given to subaerial agencies than before:

> "The more we consider the present operations of subaërial denuding agents, the more we shall be convinced that a system of hills and valleys, with all the local varieties of scenic feature that now diversify the surface of the earth, may be entirely produced by denudation, without further help from underground forces than the initial uplift into land. No matter what may be the original configuration of the mass of land, the flow of water across its surface will inevitably carve out a system of valleys and leave ridges and hills between them" (page 94).

The possibility of producing a plain by a continuance of this process is not here alluded to, but on an earlier page the aid of shore waves is called on:

> "The limit beneath which there is little effective erosion by waves and tidal currents probably does not exceed a very few hundred feet. Worn down to that limit, the degraded land would become a submarine plain, across the surface of which younger deposits might afterward be strewn" (page 92).

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* Trans. Geol. Soc. Glasgow, vol. iii, 1868, p. 153.

On later pages (137 and 138) the author continues:

> "The table-land of the Highlands has been the work not of subterranean action, but of superficial waste. The long flat surfaces of the Highland ridges, cut across the edges of the vertical strata, mark, I believe, fragments of a former baselevel of erosion. In other words, they represent the general submarine level to which the Highland region was reduced after protracted exposure to subaerial and marine denudation. The valleys which now intersect the table-land . . . have been eroded out of it. If, therefore, it were possible to replace the rock which has been removed in the excavation of these hollows, the Highlands would be turned into a wide, undulating table-land; . . . and in this rolling plain we should find a restoration of the bottom of a very ancient sea. . . . Its mountains were levelled; its valleys were planed down; and finally the region was reduced to a baselevel of erosion beneath the waves. . . . Some central tracts of higher ground may have been left as islands." *

In Geikie's "Text-book of Geology" subaerial denudation is regarded as providing a greater amount of detritus than marine denudation, and a significant modification is made of Ramsay's interpretation of plains of marine denudation. In the actual production of such plains—

> "The sea has really had less to do than the meteoric agents. A 'plain of marine denudation' is that sea-level to which a mass of land had been reduced mainly by the subaerial forces, the line below which further degradation became impossible, because the land was thereafter protected by being covered by the sea. Undoubtedly the last touches in the long process of sculpturing were given by marine waves and currents, and the surface of the plain, save where it has subsided, may correspond generally with the lower limit of wave action." †

Plains or peneplains of subaerial denudation, elevated into a new cycle of erosion without waiting to be planed off by the sea, are not explicitly considered. Under "terrestrial features due to denudation" it is stated that—

> "Table-lands may sometimes arise from the abrasion of hard rocks and the production of a level plain by the action of the sea, or rather of that action combined with the previous degradation of the land by subaerial waste. Such a form of surface may be termed a *table-land of erosion*" (page 939).

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* I have elsewhere (London Geographic Journal, vol. v, 1895, p. 139) taken the liberty of questioning the geological date assigned by Geikie to this baseleveling. He states that "the great denudation which leveled the old Highland table-land was far advanced before the close of the Old Red Sandstone period" (page 144). Undoubtedly a vast denudation was accomplished before and during that time, for the heavy strata of the Old Red lie on the greatly denuded edges of more ancient rocks; but the even table-land, restorable from the summits of the mountains and ridges of today, seems to be of more modern date, because, since the deposition of the Old Red, significant deformation has taken place, whereby a peneplain of earlier date must have been here elevated, there depressed. The table-land now recognizable appears to be the result of denudation on the deformed Old Red peneplain. There has been plenty of time for its production.

† Second edition, 1885, pp. 434, 435.

That an author who has so ably discussed the relative competence of marine and subaerial denudation should not give explicit account of plains worn down under the air and afterward uplifted and dissected, illustrates how strongly the doctrine of marine denudation has been impressed on the geologists of today.

Brief citation may be made from a number of other books and essays.

The able article, "The Denudation of the Weald,"* in which Foster and Topley did so much to advance the modern understanding of the subaerial origin of valleys, assumed that the streams of southern England began to act on an uplifted plain of marine denudation, and from this arbitrary beginning explained the transverse valleys by which the chalk escarpments around the Weald are trenched (page 473).

Maw in his essay, "Notes on the comparative structure of surfaces produced by subaerial and marine denudation,"† contrasts hills and valleys carved by rain and rivers with plains of denudation carved by the sea.

In the same way Wynne wrote "On denudation with reference to the configuration of the ground"‡ and concluded that—

> "Rain seems to act vertically, its tendency always being to produce steep ground where it is not accumulating materials. Thus we are obliged, in the absence of anything more likely to produce them, to attribute the formation of plains to the action of the sea" (page 10).

A little later Whitaker, when advocating the origin of cliffs and escarpments by subaerial denudation, said that nature "uses the sea to carve out continents and islands; rain and rivers to cut out hills and valleys."§

Mackintosh in his "Scenery of England and Wales" (1869) carries the doctrine of marine erosion to an extreme and allows hardly anything to subaerial agencies. Even the inner Triassic lowlands of England, inside of the oölitic escarpment, are ascribed to marine denudation. "The sea must have mainly given rise to the inequalities of the earth's surface, so far as they are the result of denudation" (page 292).

It appears, therefore, that the active discussion in England, of which the above extracts give some indication, did not consider the possibility of subaerial baseleveling, but was concerned chiefly with the origin of valleys by rain and rivers. Since the settlement of this question, land sculpture has not received much attention from English geologists, as the following extracts from a later period will show.

Green says, "the even surface that would result from the action of

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*Quart. Journ. Geol. Soc., vol. xxi, 1865, pp. 443–474.

†Geol. Magazine, vol. iii, 1866, pp. 439–451.

‡Geol. Magazine, vol. iv, 1867, pp. 3–10.

§Geol. Magazine, vol. iv, 1867, p. 454.

marine denudation is called a 'plain of marine denudation.'"[*] No appreciable wearing takes place below the level of the lowest tides. No mention is made of a cover of sediments as a characteristic accompaniment of the plain of denudation, and no consideration is given to the plains of subaerial denudation; only the lesser inequalities of land form are ascribed to subaerial agencies.

The edition of "Phillips' Manual of Geology," by Etheridge and Seeley (1885), briefly describes plains of marine denudation (page 131), and under subaerial denudation goes no further than to explain the origin of valleys.

Woodward, in his valuable summary of the "Geology of England and Wales,"[†] follows his predecessors in adopting the idea of marine denudation for the production of plains.

Jukes-Brown writes:

> "Plains of erosion are those which have been formed by marine erosion across the edges and outcrops of strata without reference to their inclination, flexures, or fractures. They are surfaces of planation formed by the march of the sea across the country. The limestone plains of central Ireland may be cited as an instance."[‡]

Subaerial agencies are not considered beyond the formation of valleys. For example:

> "As soon as this surface produced by marine erosion is elevated into dry land, it is subjected to the detritive action of the subaerial agencies already described, and is ultimately carved out into new forms of hill and valley" (page 565).

Detritive and erosive agencies are grouped under two heads:

> "1. Marine agencies, which act along the margin of the land, and tend to produce an approximate level surface or plain. 2. Subaerial agencies, which act over the whole surface of the land, and tend to produce a system of valleys and watersheds, hollows and relative eminences" (page 564).

In discussing breaches in the escarpments and hill ranges of the Wealden district, the same author says:

> "The only explanation of these facts is . . . marine erosion first produced a surface of planation across the whole district while it was being slowly elevated, so that this original surface sloped gently from a central line toward the north and south. The primary streams naturally followed these slopes, . . . forming the transverse valleys" (page 581).

Richthofen is the leading advocate of marine erosion among continental geologists. He treated the origin of plains of denudation, inde-

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[*] Physical Geology, 1882, p. 577.

[†] Second edition, 1887.

[‡] Handbook of Physical Geology, 1892, p. 620.

pendently of Ramsay's writings, in his great work on China, attention being led to the problem by the occurrence of unconformable marine strata lying on smooth foundations, as observed in his eastern travels. He concludes that the "oldland" platform cannot have been produced by atmospheric wasting or by running water; these agencies produce valleys separated by ridges. Truly the valleys multiply and widen and the ridges weaken, but reduction to a lowland can be reached only locally and in small dimensions. Moreover, change in the altitude of land works against complete denudation; yet, although such a result is unattainable by subaerial agencies, it may be accomplished by the waves of the sea beating on the coast. Three cases are considered: a still-stand of the land for an indefinite period, a slow elevation and a slow depression. The still-standing land would be cut inward to a limited distance, after which the waves would be exhausted on the platform of their own carving. During elevation slight effect could result, for the work would always be beginning anew. Slow depression alone can produce regional abrasion, for then the power of the waves is maintained by the continued sinking of the bottom, while detritus accumulates on it. In contrast to structural plateaus (Schichtungsplateaus), plateaus of denudation have no relation to the structures across which they are cut or to the valleys which are sunk beneath their level after general elevation. As examples, the Ardennes and the uplands of the middle Rhine are first mentioned, these being explained as producible only by sea waves; never by flowing water or other subaerial agents. Another example given is the western slope of the Sierra Nevada of California, now uplifted and dissected.*

The substance of the above is repeated in Richthofen's "Führer fur Forschungsreisende," † emphasis being given to the association of plains of denudation with unconformably overlying sediments, to which the English school directs insufficient attention. Subaerial agents are described as excavating valleys in uplifted plains of denudation, but not in producing the plains (pages 171–173, 670, 671). The prevalence of superposed streams in certain dissected uplands of abrasion is noted (pages 671, 672), but no contrast drawn between these examples and others in which the streams are systematically adjusted to the structures.

Cornet and Briart have made special study of the greatly deformed Paleozoic rocks of Belgium, which they believe once rose in lofty mountains. Although they regard subaerial agencies competent to produce the "complete ablation" of a land surface, they conclude that it was probably the waves of an encroaching sea that contributed largely to destroy what remained of their ancient mountains in Cretaceous time.‡

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* China, 1882, vol. ii, chap. xiv, sec. 3.

† Berlin, 1886, pp. 353–361.

‡ Le relief du sol en Belgique. Ann. Soc. Geol., Belg., iv, 1877, pp. 72–113.

Philippson follows Richthofen in treating plains of denudation—"abrasionsflächen"—as the result of wave action.*

The American School.

Few American writers accept the belief of the English school. The first clear recognition of the importance of subaerial baseleveling should, I believe, be credited to our geologists in the western surveys.†

Powell's "Exploration of the Colorado river" (1875) brought the American view of the capabilities of subaerial erosion more prominently forward, yet the text does not furnish brief explicit statement directly to the effect that lowlands of denudation may be produced by subaerial agencies. Extracts would lose their flavor apart from their context, but in figuring a section of the wall in the Grand canyon the beveled surface of the tilted older strata on which the horizontal Carboniferous strata lie is drawn smooth and even. The overlying beds "are records of the invasion of the sea; the line of separation the record of a long time when the region was dry land" (page 212). Here the implication is that the sea gained entrance by depression of the baseleveled land. The overlying strata are regarded as the ruins of some unrepresented land, not of the locally buried land. The explanation is precisely opposite to that given to similar structures by Richthofen.

In Powell's "Geology of the Uinta mountains" (1876) there is a similar absence of explicit account of baseleveled plains, apparently because it was not necessary to expand truisms so simple; but the chapter on degradation very clearly implies the capacity of subaerial forces to wear down mountains, however high; indeed, its burden is to show that the destruction of a lofty range is so much accelerated by steep declivity that its life cannot be much longer than that of a low range. Mountains are "ephemeral topographic forms;" all existing mountains are geologically recent (page 197). All this without once calling on the aid of sea waves.

Dutton's monograph on the "Tertiary History of the Grand Canyon district" (1882) is most characteristically American in treatment as in theme. Referring to the great unconformity near the base of the canyon walls in the Kaibab and Sheavwits plateaus, he says, on page 207, that—

> "The horizontal Carboniferous beds appear to have been laid down upon the surface of a country which had been enormously eroded and afterward submerged."

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* Studien über Wasserscheiden, 1886, p. 100.

† Marvine briefly presented the essence of the idea in 1873, but he made mention of marine action in a late stage of the process, somewhat after the fashion of the English school. Describing the east slope of the Rocky mountain front range, he wrote: "The ancient erosion gradually wore down the mass of Archean rocks to the surface of the sea, . . . the mass was finally leveled off irrespective of structure or relative hardnesses of its beds, by the encroaching ocean, which worked over its ruins and laid them down upon the smoothed surface in the form of the Triassic and other beds" (Hayden's Survey, Rept. for 1873, p. 144).

The erosion followed uplift, the deposition followed submergence when the erosion was essentially completed. Along the surface of contact there are—

> "A few bosses of Silurian strata rising higher than the hard quartzitic sandstone which forms the base of the Carboniferous. These are Paleozoic hills, which were buried by the growing mass of sediment. But they are of insignificant mass, rarely exceeding two or three hundred feet in height, and do not appear to have ruffled the parallelism of the sandstones and limestones of the massive Red Wall group above them" (page 209).

On another page (181) Dutton says:

> "The meaning of this great unconformity obviously is that after a vast body of early Paleozoic strata had been laid down they were distorted by differential vertical movements, were flexed and faulted, and were elevated above the sea. They were then enormously eroded. . . Still later the region was again submerged."

Over the rugged country thus ravaged, the later strata, perhaps 15,000 feet thick, were laid down.

Many other examples of the American view may be given. Most of them, as in the cases already cited, take no account of the possibility that the evenly abraded surface of the older terrane might be essentially the product of wave work, but tacitly assume that it resulted from subaerial erosion, followed by depression, with more or less tilting, so that the submerged area comes to be sheeted over with waste derived from some non-submerged area.

Irving concludes that in Wisconsin—

> "An amount of material vast beyond computation was removed from this ancient land before the encroachment upon it of the sea within which the [Potsdam] sandstone was deposited."*

The buried oldland is referred to as a "sub-Potsdam land surface."†

Van Hise, writing of the great unconformities below and above the Penokee series of Wisconsin and upper Michigan, implies great subaerial erosion, by which an uplifted region was reduced to a peneplain; depression, submergence and deposition of material eroded elsewhere then followed. The essentials of the explanation are that the Penokee series rests upon an ancient land surface, more or less modified by wave action at the time of submergence, but worn down from its constructional form almost entirely by subaerial agents.‡

Walcott, recognizing wave work at the margin of an encroaching sea as contributing to the formation of basal conglomerates, nevertheless explains the great pre-Cambrian land area of our country as "approaching

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*Seventh Ann. Rep. U. S. Geol. Survey, 1888, p. 402. † Ibid., p. 409.

‡ U. S. Geol. Survey, monograph xix, 1892, pp. 454–466.

the baselevel of erosion over large portions of its surface."* Moreover, it was a result of continental depression and not of erosive encroachment of the waves that the upper Cambrian sea gained its extension over the great interior of the continent (page 565). The relation of subaerial and marine agencies are here, as in so many instances, just reversed from their proportionate activities in Richthofen's scheme.

McGee was the first to present a clear statement of the vast subaerial denudation of our Atlantic slope in Mesozoic time:

> "Before the initiation of Potomac deposition, but subsequent to the accumulation of the Triassic and Rhaetic deposits and to the displacement and diking by which they are affected, there was an eon of degradation during which a grand mountain system was obliterated and its base reduced to a plain which, as its topography tells us, was slightly inclined seaward and little elevated above tide. . . . There followed a slight elevation of the land, when the rivers attacked their beds and excavated valleys as deep as those today intersecting the Piedmont plain. . . . Then came the movement by which the deposition of the Potomac formation was initiated; the deeply ravined baselevel plain was at the same time submerged and tilted oceanward."†

It appears from the foregoing examples that, in denuded plains over which unconformable sediments have been deposited, some late and small share in the work of denudation may be allowed to the shore waves as they advance over an already prepared peneplain when depression occurs; but it is otherwise with those uplifted and dissected plains of denudation upon which there is no reason to think that unconformable sediments have ever been deposited. The plateau in which the Grand canyon of the Colorado is cut is an extraordinary example of this kind. It is, moreover, notable from consisting of nearly horizontal strata, where acute observation has been needed to detect evidence of the long cycle of erosion passed through before the region was uplifted to its present altitude.

The great plateau is beveled obliquely across the Carboniferous and Permian strata, so that the undulating surface of the upland in its medial part presents Permian beds on the hills and Carboniferous beds in the hollows; but to the south, where the strata gently rise, the whole surface is Carboniferous; to the north, where the strata sink, the surface is entirely Permian.

> "We may suppose that this entire region, at the epoch at which the great denudation of the Mesozoic system approached completion, occupied a level not much above the sea. Under such circumstances it would have been at what Powell terms baselevel of erosion. The rivers and tributaries would no longer corrade their channels. The inequalities which are due to land sculpture and the general process of erosion would then no longer increase, and the total energy of erosion would be

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* Twelfth Ann. Rep. U. S. Geol. Survey, 1891, p. 562.

† Three formations of the middle Atlantic slope. Am. Jour. Sci., vol. xxxv, 1888, p. 142.

occupied in reducing such inequalities as had been previously generated. During periods of upheaval, and for a considerable time thereafter, the streams are cutting down their channels, and weathering widens them into broad valleys with ridges between. The diversification so produced reaches a maximum when the streams have nearly reached their baselevels; but when the streams can no longer corrade, and if the uplifting ceases, these diversifications are reduced and finally obliterated. Such, I conceive, was the case here. . . . The entire region was planed down to a comparatively smooth surface." *

Willis first called attention to the occurrence of an uplifted and dissected peneplain of subaerial denudation in the mountains of North Carolina,† and Hayes and Campbell have since then shown the great extent and area of this ancient land surface.‡ Willis and Hayes have lately described the northern and southern Appalachians, § giving much attention to the essential extinction of the mountains, except in the Carolina highlands, in late Cretaceous time. The first author writes of the lowland thus produced: "The land was flat, featureless and very slightly elevated above the sea" (page 189). The second author writes: "The whole region was reduced to a nearly featureless plain, relieved only by a few groups of monadnocks where the highest mountains now stand" (page 330).

Emerson writes of the Berkshire hills in western Massachusetts:

> "Erosion planed away the mountains to the general level, which can still be seen in the average level of the plateau, pitching slightly east. * * * When this peneplain was formed it was doubtless horizontal and near the sealevel, and was what is called a baselevel." ‖

Salisbury says that the even crest-lines of the New Jersey highlands tell of "mountainous elevations reduced to a peneplain near the level of the sea." ¶

Not only the tilted rocks of the Alleghenies and of the older Appalachian belt, but the horizontal strata of the Allegheny plateau are regarded as having been baseleveled, or almost so, before their present uplift and dissection was gained. See, for example, the account of the Cumberland plateau in Tennessee by Hayes.**

Griswold has recognized a greatly dissected peneplain in the even crested ridges of the Arkansas novaculites, and has associated the warping of the great peneplain of which his special district was a part with the origin of the lower course of the Mississippi in late Mesozoic time.††

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* Grand Canyon District. U. S. Geol. Survey Monogr., II, 1882, p. 119.

† Round about Asheville, Nat. Geog. Magazine, vol. i, 1889, p. 297.

‡ Geomorphology of the southern Appalachians, ibid., vol. vi, 1894, p. 69.

§ Nat. Geog. Monographs, vol. i, 1895, nos. 6 and 10.

‖ Hawley sheet, Geol. Atlas U. S., 1894.

¶ Geol. Survey New Jersey, 1894 (1895), p. 8.

** Sewanee sheet, Geol. Atlas U. S., 1895.

†† Geol. Surv. Arkansas, 1890, vol. iii, p. 222; Proc. Bost. Soc. Nat. Hist., vol. xxvi, 1895, p. 478.

Keyes[*] and Hershey[†] have recently described the upland of the Ozark plateau in Missouri as an uplifted and dissected peneplain. The region has an essentially horizontal structure, like the Allegheny plateau, with which it is in many ways homologous. The latter author tells of residual hills or monadnocks which still surmount the upland plain, and of faint inequalities of form that seem to mark "the hydrographic basins of the streams which flowed on the Cretaceous lowland plain;" but as a whole the region was "a low, marshy plain of very slight relief, probably nearly at sealevel."

Darton describes the Piedmont area of Virginia as—

> "An undulating plateau carved in greater part in crystalline rocks . . traversed by rivers which flow in gorges. . . It is now very clearly recognized that the Piedmont plateau is a peneplain of Tertiary age. . . There is a system of very low, flat divides coincident with those of the present drainage system." [‡]

Keith also describes the formerly even surface of the Piedmont belt in which the valleys of today are incised, as a Tertiary baselevel of subaerial origin. [§]

The bevelled western slope of the Sierra Nevada, regarded as an upturned plain of marine abrasion by Richthofen, is ascribed by Gilbert,[‖] Leconte,[¶] Lindgren,[**] Diller[††] and others to subaërial denudation; but Lindgren makes it clear that when the region stood lower it was not worn smooth enough to be called a peneplain; "the declivities and irregularities of the old surface are too considerable for that."

Diller describes a peneplain formed on the upturned Cretaceous rocks of northern California and now dissected by various streams:

> "The production of such a broad, uniform plain by the erosion of rocks varying greatly in hardness could only be accomplished on a very gentle slope near the level of the controlling water body, and we may therefore properly consider this plain a baselevel of erosion." [‡‡]

Lawson presents an instructive account of an uplifted and dissected peneplain beveled across upturned strata in northern California. Waterworn gravels occur on the ridges of the dissected upland. They "can only be interpreted as remnants of the stream gravels of the ancient peneplain."[§§]

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[*] Geol. Surv. Missouri, vol. viii, 1894, pp. 330, 352.
[†] American Geologist, vol. xvi, 1895, p. 338.
[‡] Chicago Jour. Geology, 1894, vol. ii, pp. 568–570.
[§] Fourteenth Ann. Rept. U. S. Geol. Survey, 1894, p. 369.
[‖] Science, vol. i, 1883, p. 195.
[¶] Bull. Geol. Soc. Am., vol. 2, 1891, p. 327.
[**] Ibid., vol. 4, 1893, p. 298.
[††] Chicago Jour. Geol., vol. ii, 1894, p. 34.
[‡‡] Fourteenth Ann. Rept. U. S. Geol. Survey, 1894, p. 405.
[§§] University of California; Bull. Dept. Geol., vol. i, 1894, p. 244.

G. M. Dawson describes an ancient peneplain, now an elevated and dissected plateau, in the Rocky Mountain region of Canada:

> "Climbing to the level of this old plateau, or to that of some slightly more elevated point about the fiftieth or fifty-first parallel of latitude, the deep valleys of modern rivers with other low tracts are lost sight of, and the eye appears to range across an unbroken or but slightly diversified plain, which, on a clear day, may be observed to be bounded to the northeast, southwest and south by mountain ranges with rugged forms, and above which in a few places isolated higher points rise, either as outstanding monuments of the denudation by which the plateau was produced, or as accumulations due to volcanic action of the Miocene or middle Tertiary period." *

After explicitly considering the alternatives of marine and subaerial erosion, the author decides against the former, because the plateau district is not accessible to the sea, and because there are no marine strata thereabouts referable to the period when the peneplain was formed. The river system of the region—

> "aided by other subaerial agencies, cut down almost its entire drainage basin till this became a nearly uniform plain, with some slight slope in the main direction of the river's flow, but of which the lowest part approximately coincided with the sea-level of the time. . . . After reaching this baselevel of erosion the rivers would, of course, be unable to do more than serve as channels for the conveyance of material brought into them from the surrounding country, which, wherever it stood above the general level, was still subject to waste. The valleys became wide and shallow, and the surface as a whole assumed permanent characters." †

My own studies lead me to believe that subaerial denudation has reduced various mountainous or plateau-like uplifts to lowland peneplains. ‡

A considerable number of extracts might be presented from the works of foreign writers to show that the idea of marine denudation is on the whole less favorably received by continental than by English geologists; but the features of land form and the processes of land sculpture have not been studied in Europe with the attention that has been given to stratigraphic succession or to the problems of paleontology and petrography. Regions that are known to be uplands of denudation are often described with abundant detail as to their structure, but with the scantiest reference to the conditions of their topographic development.

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* . . . The Rocky Mountain region in Canada . . . , Trans. Roy. Soc. Can., viii, 1890, p. 11.

† Loc. cit., p. 13.

‡ The following articles may be referred to: Relation of the coal of Montana to the older rocks (Tenth Census U. S, vol. xv, 1886, p. 710); Topographic development . . . of the Connecticut valley (Am. Jour. Sci., vol. xxxvii, 1889, p. 430); Geographic development of northern New Jersey (with J. W. Wood, Proc. Boston Soc. Nat. Hist., vol. xxiv, 1889, p. 373); Rivers of northern New Jersey (Nat. Geog. Mag., vol. ii, 1890, p. 6); Topographic forms of the Atlantic slope (Bull. Geol. Soc. Am., vol. 2, 1891, p. 557); Physical geography of southern New England (Nat. Geog. Monogr., vol. i, 1895, p. 276); Development of certain English rivers (London Geog. Jour., vol. v, 1895, p. 140).

A characteristic example of this manner of treatment is found in the valuable works by Lepsius on the mountains of the upper and middle Rhine,* in which the Schiefergebirge and other ancient mountains are fully treated as to structure, although little is said of their form and still less of the origin of their form.

The following citations are from works in which land form and sculpture are more fully considered.

The increasing importance attributed by Sir A. Geikie to subaerial agencies in his later writings has already been noted. Professor James Geikie goes further in this direction and says:

> "Valleys continue to be deepened and widened, while the intervening mountains, eaten into by the rivers and their countless feeders and shattered and pulverized by springs and frosts, are gradually narrowed, interrupted and reduced until eventually what was formerly a great mountain chain becomes converted into a low-lying undulating plain." †

Gosselet, in his comprehensive monograph on the Ardennes, says that the tilted, folded and faulted strata of their uplands have been, as it were, planed down by the combined action of atmospheric disintegration and pluvial wearing. Both the Jurassic and Cretaceous formations are described as lying on oldland soils, where they overlap the Paleozoic strata.‡

The elaborate treatise on "Les formes du terrain" (1888), by de la Noë and de Margerie, clearly maintains that pluvial denudation may not only produce valleys, but it may wear down the divides between the valleys (page 106). The escarpments or cross-valleys of the Weald in southern England may be explained without calling on marine erosion, as most of the English geologists have done (pages 135, 136). Plateaus of abrasion, without a cover of unconformable strata, may be "simply the result of prolonged subaerial erosion." If unconformably covered, it still remains to be seen how far the abraded surface is—

> "The modification by wave action of a hardly different surface, produced by the prolonged work of streams which had long before attained faintly graded slopes, and which had by the aid of atmospheric agents almost completely destroyed preexisting inequalities of form" (page 188).

Penck concludes that the final aim of subaerial denuding agents is to reduce a land almost completely to a plain,§ but his account of the Schiefergebirge of the middle Rhine does not explicitly state whether the "abrasionsplateau" of their uplands is of marine or subaerial origin.||

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* Die Oberrheinische Tiefebene und ihre Randgebirge, Forschungen zur deut. Landeskunde, i, 1885, 35-91; Geologievon Deutschland, 1887.

† Mountains, their origin, growth and decay: Scot. Geog. Mag., vol. ii, 1886, p. 160.

‡ L'Ardenne. Mém. Carte géol., France, 1888, pp. 802, 808, 837.

§ Das Endziel der Erosion und Denudation, Verh. viii deut. Geographentag, 1889, pp. 91-100.

|| Landerkunde des Erdtheils Europa, i, 1887, p. 316.

In his compendious volumes on the "Morphologie der Erdoberfläche" (1894), he considers plains of marine and of subaerial denudation, both as to process of origin and as to derivative forms, after elevation and dissection, but criteria for their discrimination are not discussed.*

De Lapparent, president of the French Geographical Society, has advocated subaerial erosion as the means of denuding the Ardennes and the Central plateau of France, † and later says:

> "La notion des pénéplaines est extremement féconde, et ce n'est pas un de ses moindres mérites d'avoir porté le coup de grâce à la théorie des plaines de dénudation marine, si fort en honneur de l'autre coté du détroit." ‡

COMPARISON OF THE TWO SCHOOLS.

It is noteworthy that, with few exceptions, the more recent writers here quoted do not discuss both processes by which smoothly abraded plains, whether buried or bare, may be produced, but directly announce their conclusion as to the origin—by marine or by subaerial agencies—of the surface under consideration. This, of course, implies that they regard the question as settled, just as for some time back it has been the habit of geologists on finding marine shells in stratified rocks to conclude, without reviving the discussions of earlier centuries, that the strata are of marine origin, and that their present position indicates a change in the relative attitude of the land and sea. But in this latter example all geologists are today agreed, while in the problem of the origin of plains of denudation each writer follows only the conclusion of his own school, not the conviction of the world. *It is chiefly to arouse attention to this aspect of the problem that the present review is undertaken.*

It is further noteworthy that, with few exceptions, the authors who discuss the matter at all do not attempt to discriminate between the two possible classes of denuded surfaces by searching for features peculiar to one or the other, but content themselves with *a priori* argument as to the possibility of producing plains by marine or subaerial agencies.

There is, however, a certain difference of attitude in the two schools regarding the doctrine of the other. The English school hardly considers at all the ability of subaerial agencies to produce smooth plains of denudation; their discussion of the question turned really on the possible origin of valleys by subaerial agencies. The American school does not, as far as I have read, deny the ability of marine agencies, but attributes greater ability, especially far in continental interiors, to subaerial agencies; their discussion of the question postulates the subaerial origin of ordinary

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* Vol. ii, pp. 145, 181, 489.

† L'age des formes topographiques, Rev. des quest. scient., Oct., 1894.

‡ La géomorphogénie, ibid., April, 1895.

valleys as a matter already proved, and goes on from this to the possible ultimate result of the valley-making processes. Again, the English school denies, tacitly or directly, the probability or even the possibility of a period of still-stand long enough for essentially complete subaerial denudation close to sealevel, but assumes the possibility of a period of still-stand or of slight depression continuous and long enough to allow the sea waves to plane off the sinking lands. The American school tacitly questions the occurrence of great erosive transgressions of the sea during either a still-stand or a slow depression of the land, but admits the possibility of essentially complete subaerial denudation to an average sealevel, above and below which the land long hovers in many minor oscillations before a new attitude is assumed by great depression, elevation or deformation. It should be borne in mind that the depressed and buried or the uplifted and dissected plains of denudation whose origin is in question are in no cases geometrical planes; they nearly always possess perceptible inequalities, amounting frequently to two or three hundred feet; but these measures are small compared to the inferred constructional relief of earlier date, or compared to the deep valleys often eroded beneath the plain if it has been uplifted. By whatever process the so-called "plain of denudation" was produced, an explanation that will account for a peneplain of moderate or slight relief is all that is necessary. Absolute planation is so rare as hardly to need consideration here.

In no respect is the contrast between the two schools more strikingly shown than in the beliefs concerning the cover of unconformable strata that lie or are supposed to have lain upon an oldland. The continental members of the English school generally regard these strata as an essential result of the process of marine denudation during slow depression; if such strata are absent from a dissected plateau, their absence is explained by denudation after uplift. The American school does not give the cover of unconformable strata an essential place in the problem; if present, it is generally ascribed to deposition following the submergence of a region already for the most part baseleveled by subaerial agencies.

REVIEW OF THE *A PRIORI* ARGUMENT.

It may be noted that the value of marine agencies gained a high reputation for effective work before subaerial agencies were recognized as significantly affecting the form of the land, and that from that time to the present the importance of the latter agencies has been steadily increasing in the minds of geologists. The manifest work of waves on a bold coast was perceived at a time when the production of valleys by rain and rivers was scouted. Today it is not so much that the absolute strength of marine erosion is given a smaller value than heretofore, but that the relative importance of subaerial erosion is rated much higher than at the beginning of the century. While the sea works energetically along a line, subaerial forces work gently over a broad surface. Chiefly for this reason Geikie concludes that "before the sea, advancing at a rate of ten feet a century, could pare off more than a mere marginal strip of land between 70 and 80 miles in breadth, the whole land might be washed into the ocean by atmospheric denudation."*

A slight movement of elevation usually sets the sea back to begin its work anew on the seaward side of its previous shoreline, but such an elevation only accelerates the work of subaerial denudation all over the elevated region. The waves on the seashore shift their line of attack with every slight vertical movement of the coastal region; but the subaerial forces over large continental areas gain no notice of slight movements until a considerable time after they have been accomplished, and hence they perform their task only with reference to the average attitude of the land. Observers near a shoreline naturally have their attention directed to the unsteadiness of the land, as indicated by marks of many recent changes of land level; hence they are perhaps indisposed to admit that any land has ever stood still—or oscillated slightly above and below an average attitude—long enough to be nearly or quite baseleveled by subaerial agencies. They prefer to think that the sea is, in spite of its many stops and starts, the great leveler of the lands.

Some have intimated that the insular position of English observers has led them to exaggerate the relative power of the sea. Thus W. T. Blanford, after much experience in India and elsewhere, as well as at home in England, writes:

> "It is not surprising that the power of rain and rivers should be recognized with difficulty in regions where their effects are comparatively so dwarfed as in the British isles, while the power of marine denudation is at its maximum from the enormous coastline exposed and the small amount of detritus furnished for its protection by rivers of small length and in which floods are of exceptional occurrence." †

But even this well practised observer contended only for the subaerial origin of valleys, not of plains also. On the other hand, those whose studies have been directed chiefly to large interior areas seldom have occasion to observe the action of energetic shore waves, and hence are apt to attribute relatively little importance to their work. The small share of attention recently given by Powell to shore waves and coastal forms in a general discussion of physiographic processes and features is perhaps thus explained. ‡ The citation from Dawson, given above, is

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* Text-book, 1885, p. 432.

† Geol. and Zoöl. Abyssinia, 1870, p. 158, note.

‡ Nat. Geog. Monographs, vol. i, 1895, nos. 1 and 2.

an especially good illustration of the manner in which large continental surroundings may affect the opinions of an observer who, from certain associations, might be expected to follow the insular school.

Although mature deliberation and good judgment may lead through *a priori* argument to a safe conclusion in many problems, the method is of difficult application here on account of the great number of variable factors whose appropriate values can be hardly determined. It is probably by reason of assigning different values to variable factors that the opposite conclusions summarized above have been reached.

STATEMENT OF THE *A POSTERIORI* ARGUMENT.

In attempting to decide by arguing from effect to cause whether evenly denuded regions have been worn down by subaerial or marine agencies, let us try to stand on a provisional Atlantis, hoping that it may give steady support long enough for us to gain an unprejudiced view of the opinions that are so generally accepted on the lands to the east and west. From this neutral ground let us attempt to deduce from the essential conditions of each explanation of the problem as many as possible of its essential consequences, and then confront these consequences with the facts. The measure of accordance between consequences of theory and facts of observation will then serve as a measure of the verity of the theory from which the consequences are derived. No final decision can be reached in many cases; for, however clearly the consequences may be deduced, the facts with which they should be compared are often beyond the reach of observation. In such cases it is advisable to announce indecision as clearly as decision is announced in the others.

As far as I have been able to carry the analysis of the problems, it is more difficult to find positive criteria characteristic of plains of marine denudation than of plains of subaerial denudation; hence I will take up the latter class first. It should be remembered, however, that in each class of plains both classes of agencies may have some share, one preponderating over the other.

CONSEQUENCES OF SUBAERIAL DENUDATION.

Imagine a region of deformed harder and softer strata raised to a considerable elevation. Then let the land stand essentially still, or oscillate slightly above and below a mean position. The rivers deepen their valleys, the valleys widen by the wasting of their slopes, and the hills are slowly consumed. During this long process a most patient and thorough examination of the structure is made by the destructive forces,* and whatever is the drainage arrangement when the rivers begin to cut their

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*See Bearing of physiography on uniformitarianism. Bull. Geol. Soc. Am., vol. 7, 1895, pp. 8–11.

valleys a significant rearrangement of many drainage lines will result from the processes of spontaneous adjustment of streams to structures. This involves the adjustment of many subsequent streams to the weaker structures and the shifting of many divides to the stronger structures. Adjustment begins in the early stages of dissection, advances greatly in the mature stages, and continues very slowly toward old age, while the relief is fading away. Indeed, when the region is well worn down some of the adjustments of maturity may be lost in the wanderings of decrepitude, but this will seldom cause significant loss of adjustment except in the larger rivers. Now, if a region thus baseleveled or nearly baseleveled is raised by broad and even elevation into a new cycle of geographical life, the rivers will carry the adjustments acquired in the first cycle over to the second cycle. Still further adjustment may then be accomplished. The master streams will increase their drainage area in such a way that the minor streams will seldom head behind a hard stratum. In a word, the drainage will become more and more longitudinal and fewer and fewer small streams will persist in transverse courses. All this is so systematic that I believe it safe to assert that the advanced adjustments of a second cycle may in many cases be distinguished from the partial adjustments of a first cycle. It should be noted further that in the early stages of the second cycle the residual reliefs of the first will still be preserved on the uplands. and that they will be systematically related to the streams by which the dissection of the upland is in progress, as noted in the examples described by Darton and Hershey.

It is manifestly impossible to apply what may be called the river test to plains of denudation upon which a cover of unconformable sediments is spread; but, before assuming that such buried plains are of marine origin, their uppermost portion next beneath the cover should be examined to see if it presents indications of secular decay before burial; and, if so, a subaerial origin for the plain may be argued. Certain aspects of this division of the subject have been discussd by Pumpelly.* Another matter of importance is the character of the undermost layers of the cover. If these are fresh-water beds a subaerial origin for the plain on which they rest may be inferred. The Potomac formation offers an example of this kind. †

Consequences of marine Denudation.

Now suppose that a region of disordered structure is partly worn down by rain and rivers and is smoothly planed across by the sea during a time of still-stand or of gradual depression. The land waste gained in the

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* Bull. Geol. Soc. Am., vol. 2, 1891, p. 211.

† McGee: Am. Jour. Sci., vol. xxxv, 1888, p. 137; Fontaine: Monogr. xv, U. S. Geol. Survey, 1889, p. 61.

later attack will be spread off-shore on the platform abraded in the earlier attack. The basal strata of the unconformable cover thus formed must indicate their marine origin and must be appropriately related in composition and texture to their sources of supply. The drainage systems of the land will be essentially extinguished by the encroaching sea. When the region rises, with the cover of new sediments lying evenly on its smoothed back, a new system of original consequent streams will take their way across it. If the elevation be sufficient, the streams will incise their valleys through the cover of new sediments and in time find themselves superposed on the "oldland" beneath. As time passes, more and more of the cover will be stripped off; at last it may disappear far and wide, although the stripped surface of the oldland may still retain a generally even sky-line as a memorial of its once even denudation. Now, in this case, the rivers by which the dissected plateau is drained will have at most only a very slight adjustment to its structure. Their courses will have been inherited from the slope of the lost cover; they will at first run at random across hard and soft structures; a little later some adjustment to the discovered structures will be made, but as long as the even sky-line of the upland is recognizable, only the incomplete adjustments appropriate to the adolescent stage of denudation can be gained.

EXAMPLES OF DISSECTED UPLANDS WITH ADJUSTED DRAINAGE.

This essay has already reached so much more than its expected length that it will not be possible to give extended space to the consideration of specific examples. This is, however, no great disadvantage, inasmuch as the number of examples in which the problem has been considered in relation to drainage arrangement and other discriminating features is very small. The various articles already referred to concerning the geographical development of the Appalachian region treat this aspect of the subject with some care; to these may be added my paper on "Certain English rivers," in which it seems to me that there is shown some ground for the consideration of the alternative to the usual English view. Of the Ardennes it may be briefly said that systematic longitudinal and transverse streams are well developed in certain areas, and in those parts, at least, there does not appear direct evidence of marine transgression. Sheets 48 and 54 of the Belgian topographical map (scale, 1 : 40,000) exhibit these features very clearly. On the other hand, the branches of the Rhine and the Moselle in the Schiefergebirge suggest superposition from a lost cover, as mapped on the sheets of the Karte des Deutschen Reichs (scale, 1 : 100,000).

It is manifest that many plains of denudation, now uplifted and more or less dissected, may be found in which no simple test based on the presence of superposed streams will serve to settle the question of marine origin. Indeed, it appears to me a difficult matter to adduce any examples of extensive plains of denudation whose origin is demonstrably marine and to whose planation subaerial agencies have not contributed the greater work. A region may be almost reduced to baselevel by subaerial denudation when the transgressing sea completes the work, extinguishing the adjusted valleys and introducing superposed streams in the next cycle of denudation. A region well baseleveled under the air may by quick depression suffer rapid ingression of the sea, whose shore waves will during depression nowhere reside long enough to perform a significant amount of abrasion. When the region is thus submerged and stands again relatively quiet, the waste from a non-submerged area, gained both by marine and subaerial denudation, may be spread over the denuded and depressed plain, and when afterwards elevated with an unconformable cover that will induce superposed drainage, all trace of former adjustments will be lost; yet here the planation was not marine. A district of superposed drainage in central New Jersey, where the Amboy clays once spread over the red shales and sandstones of the Trias, may probably be taken as an example of this kind. Superposed rivers cannot, therefore, always be taken to prove that the uplands which they dissect are uplifted plains whose denudation was chiefly performed by the sea.

Regions of essentially horizontal structure normally have wandering streams; no systematic arrangement of drainage is here to be expected. Discrimination in such regions has seldom been attempted between examples of one cycle of subaerial denudation, now adolescent or mature, and examples of two cycles, the first having reached old age and the second now being in its adolescence or maturity. The sky-line would be smooth and even in examples of either class: in the first, because its original constructional form was a plain; in the second, because it was planed down essentially smooth at the close of the cycle preceding the current cycle. It is, however, sometimes possible in regions of horizontal structure to recognize the records of old age reached in a former cycle by a slight discordance between the general upland surface and the attitude of the strata; or by the association of the region with an adjacent region of tilted structure where indications of an earlier cycle of subaerial denudation are manifest, both these tests being applicable in the Allegheny plateau; or by the arrangement of the faint residual relief of the uplands, where not trenched by young or adolescent streams, this test having been applied in the Piedmont district of Virginia, in the Ozark plateau of Missouri, and in the Great plains of eastern Montana. Further study of many other examples is desirable.

SAND POINT, PRUDENCE ISLAND, RHODE ISLAND

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CUSPATE FORELANDS

BY F. P. GULLIVER

(Read before the Society December 27, 1895)

CONTENTS

INTRODUCTION.*

During my work at Cambridge with Professor Davis attention has been directed to shorelines and the forms which are systematically developed during successive stages of shore evolution along the common border of the land and sea. It was early seen that a distinction is needed between the oldland, all those preëxisting portions of more or less wasted formations, and the newer land, the coastal plain, which borders and is composed of the detritus from the oldland. In a similar manner a distinction is needed between the forms cut and those accumulated in the course of shore evolution. At the beginning of a cycle the waves attack the coast at all points, cutting or nipping back the initial† form of the land into a cliff; while at a later stage transportation of material alongshore begins and the waste from the edge and bottom of the land, together with the river sediment, is built out at certain points in front of the older mainland in deposits of various shapes, which are appropriately grouped together under the general term forelands.‡

The word foreland has been locally applied to a few headlands, as the Foreland in Devon on the Bristol channel, the North and South Forelands in Kent county, England, and the Bloody Foreland in northwestern Ireland. As such projecting promontories of the mainland have the well established generic term of "headland" in geography, the use of the word foreland in a few places as the local name for certain headlands

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* LIST OF ABBREVIATIONS.

Austr. = K. u. K. militär-geographisches Institut, Austria, 1 : 75,000.
C. S. = United States Coast and Geodetic Survey, various scales.
Denm. = Generalstabens Kort over Danmark, 1 : 100,000
Eng. = Ordnance Survey, England, 1 : 63,360.
G. S. = United States Geological Survey, 1 : 62,500.
Germ. = Karte des Deutschen Reiches, 1 : 100,000.
Holl. = Topographische en militaire kaarte van het koningrijk Nederlanden, 1 : 50,000.
H. O. = Hydrographic Office, United States Navy, various scales.
Ital. = Instituto geografico militare, Italy, 1 : 100,000.

† *Initial*, as used above, is here proposed as the technical term to define the form at the beginning of any geographic cycle. Any dynamic process which produces a change in the relative position of land and sea may interrupt a cycle at any stage of development and cause the initial form of the new cycle. Later stages and forms may be called appropriately *sequential*. These terms are offered to avoid the misconception, on account of their vernacular meaning, of the terms *constructional* and *destructional*, hitherto used by some writers for the identical ideas.

‡ Consult Penck : Morphologie der Erdoberfläche, Stuttgart, 1894, and compare his use of Vorland and Vorgelagerte, vol. ii, pp. 17, 444, 548; also J. A. de Luc : Geological Travels, 1810, vol. i; John Wiggins : The Practice of embanking lands from the Sea, 1852, pp. 198–200.

does not seem to the writer to be any serious objection to the generic use of the term here proposed. The etymology of the two parts of the compound suggests the idea of being built in front of the preëxisting mainland.

Summary.

In this paper will be considered those forelands which present a more or less sharply pointed form, whose two sides are bounded by shore curves, concave seaward, and which may include within the limits of the deposit water bodies of various kinds and sizes. These are called cuspate forelands. Facts are brought forward to show that these cuspate forelands may be divided into three main classes, namely, current, tidal, and delta, according to what appears to be the determining factor in their production. There are also two subvarieties which are due to steps in the process of island-tying, one before a bar completely ties an island to the mainland, and the other when the island is nearly consumed.

Sea Attack.

Before discussing the deposits themselves, some of the facts regarding the action of the sea upon the land should be considered.

The forms of the littoral zone are best understood when regarded as marking stages in the consumption of the land by the sea, as a result of the intention of the sea to reduce the land at last to a submarine platform lying beneath the baselevel controlling subaërial denudation. The submarine platform is the ultimate product of the sea action, while the peneplain is a very late stage of subaërial waste; and as the peneplain approaches but never quite reaches its limiting geometrical plain, sea-level or baselevel, so the submarine platform must have a similar limiting plane, which for lack of a better term is here called *wave-base*. The discussion of wave-base will be left to a later paper.

The agents of the sea are the waves, tides, and currents. Writers differ widely in what they attribute to each of these three agents, and a discriminating study of the work of the three is much needed. The present writer is inclined to attribute the attack of the sea largely to the waves, and its transporting action largely to the tides and currents. For the present discussion it is necessary simply to distinguish between the three actions: Attack, on and offshore transportation, and alongshore transportation.

At the beginning of a cycle, when a new portion of the land is presented to the sea, the sea is occupied principally in attack, the waste from the initial coast or shallow bottom being deposited by the offshore currents.*

SEA TRANSPORTATION.

At a later stage, when the supply of waste has increased beyond the power of the currents to immediately deposit it offshore, transportation alongshore will become more important and the growth of forelands may take place in certain places. The tendency of shore currents is undoubtedly to form curves in the shoreline which will be satisfactory to the particular current acting. In a general way the radius of curvature of the shoreline will be proportional to the strength of the alongshore current.

The writer makes the following distinction between the sea action upon the inner † shoreline, which includes the more protected coasts of bays, drowned valleys, sounds, channels, etcetera, and its action upon the outer † shoreline, which is that of the exposed coasts of the ocean. The ocean currents have little direct effect upon the inner shoreline, and the wind has not opportunity to develop current eddies of large radius of curvature upon inland waters. In these narrow arms of the sea the tidal currents are the preponderating force. The ocean current and the local wind current must be of less importance here than the tidal currents. It may be stated as a general principle that the most effective agent of shore development upon the inner shoreline of drowned topography is the tidal current. Broad bays form a middle ground where any of the three forces may be the strongest. Upon the outer shoreline the ocean eddy currents are the most effective, while upon lakes and inland tideless seas the local wind currents are the most important factor.

CURRENT CUSPS.

FORM.

The four great capes along the eastern coast of the United States, namely, Hatteras, Lookout, Fear, and Canaveral, are so well known and have been so frequently mapped that a general description is here unnecessary. The theory of current cusp formation will therefore first be considered and the more detailed facts of form introduced afterward.

BACKSET EDDIES.

The ocean circulation is made up of great eddies, which in turn set up smaller eddies between the main current and the coastal border. These

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* For the method of wave attack, see Gilbert: Monograph I., U. S. Geological Survey, chap. ii, with references; Lyell: Principles of Geol., 11th ed., 1872, vol. i, chaps. xx–xxii; Le Conte: Elements of Geol., 2d ed., 1882, pp. 31–43; Penck, loc. cit., vol. ii, pp. 460–497, with references.

† See Penck, loc. cit., vol. ii, p. 551.

smaller currents revolve in the reverse direction to that of the great circulation. Eddies of this kind are appropriately called backset eddies. When more waste is supplied than the on and offshore components of the total sea action can spread over the bottom, the alongshore component will deposit it where it encounters dead water or water moving with less velocity than the current itself. In a backset eddy system of circulation such comparatively dead water will occur where the alongshore currents curve from the shore toward the deep sea. Slight inequalities of outline in the newly born land may break the backset current into eddies of varying radius of curvature. Between such eddies there would be formed a triangular space of comparatively dead water, in which the growth of a cusp might be expected. Given the backset eddies and the inequalities, or even a straight shoreline, and cuspate forelands at least in outline could be formed, for a detritus-laden current must deposit the surplus of its load along its margin where it comes in contact with quiet water.

COMBINATIONS OF CURRENTS.

There are three possible pairs of currents which might produce cuspate forelands upon the outer shoreline: First, both currents flow toward the land; second, both currents flow toward the water; third, one current flows toward the land and the other toward the water.

The first will not cause a cusp unless the currents come to the land laden with detritus, or else one or both of the currents be reversed for a portion of the time, bringing out waste from the land.

Mr Gilbert figures a V-bar on the Bonneville shoreline, where both the currents seem to have flowed from the land.* He says:

> "All that I could observe in the case of the fossil shores was the direction of the *net* movement, and where I found no evidence on that point I drew no arrows. The evidence consisted of difference in size of pebbles, difference in amount of rounding, and difference in height of embankment. I remember that in case of figure 4, for example, the right-hand limb of the V is a foot or two higher than the left-hand, and this feature was so often found associated with other evidence of transportation in the direction indicated by the arrows that I may possibly have used it in some cases without the other evidence." †

There is probably movement in both directions along all forelands at different times and the form shows in which direction the dominant movement has taken place. The dominant movement may not always correspond to the prevailing movement alongshore. A few severe storms causing a strong current from the right during one month might deter-

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* Monograph I., U. S. Geological Survey, p. 58, pl. vii, figure 2.

† Letter to writer.

mine forms which a weak current from the left prevailing for eleven months of the year would not be able to efface.

According to the third scheme, a current flows toward the land upon one side of the foreland, while upon the other side a current flows toward the sea. As has been pointed out, such an arrangement would result if a dominant current alongshore were broken by projections of the land into several eddies.

Such a system of backset eddies has been suggested by Mr C. Abbe, Jr.,* as the cause of the three great Carolina cusps, capes Hatteras, Lookout, and Fear. Such currents seem to be proved by observations along the shore. In the "Geological Survey of South Carolina for 1848" Mr Tuomey describes "an eddy current which washes the coast southwardly."†

In Beaufort harbor, North Carolina, the shifting of the bar to the left between 1854 and 1857 and between 1862 and 1864 was observed by the Coast Survey.‡

Professor Shaler, in summing up the observations along the Atlantic coast from Chesapeake bay to Florida, says that the prevailing movement of the sand is from north to south.§

The writer has the very distinct remembrance of reading that coasting vessels go south along the Carolina shore near the coast because they find a southward-flowing current, but he is unable to refer to the statement definitely.

CONSEQUENCES OF THEORY.

If a cuspate foreland were formed in the dead water between two currents revolving in the same direction, the transportation of material alongshore would be either from right to left or from left to right; that is, the dominant movement would be in one direction, though local storms, winds, tides, or currents might carry materials for short distances in the opposite direction. The geologic evidence from kind, size, rounding and position of pebbles composing the beach of the foreland would doubtless settle in the field the question of direction of transportation. There are, however, facts of geographic form which may be expected to result from this arrangement of currents. These facts can be observed upon topographic maps, and from them we may infer the dynamic actions. The three criteria of form from which we may infer the dominant current alongshore are offset, overlap, and stream deflection. The three usually

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* Proc. Bost. Soc. Nat. Hist., vol. xxvi, 1895, p. 469, and figure 1.

† Page 190.

‡ Appendix 16, 1857, p. 152; appendix 6, 1864, p. 57.

§ Geol. Hist. of Harbors, Thirteenth Ann. Rep. U. S. Geol. Survey, 1891–'92, p. 128.

occur together, but each is found alone; therefore to make the point more emphatic each will be considered by itself.

In all the figures used in this paper the water is on the right and the land on the left without regard to the compass bearing in those figures drawn from actual localities. The older mainland is cross-hatched, while the forelands are left white. The observer is supposed to look from the point of view of the sea as it attacks the land; therefore the two sides of the figures will be spoken of as the right and left respectively as seen from the sea looking toward the land.

Types of offset without accompanying overlap are given in figure 1. Overlaps are commonly accompanied by offsets of the shore curves in the same direction, as is markedly the case in Fire Island inlet, Long island (C. S., 119). One shore curve offsets another when the curve itself or the continuation of the same passes to seaward of the next succeeding shore curve. When this offset is slight it may be perceived by looking along the shore curve putting the eye close to the map.

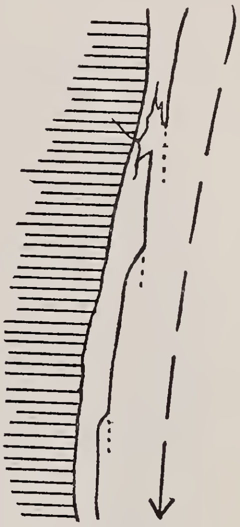

FIGURE 1.—*Offsets.*

The typical example of offset without overlap is on the west coast of Jutland (Denm., Thisted), where the currents are known to be from the south, which is in this case the right.* The right shore curve systematically offsets the left along all the western coast of Denmark.

Many examples of similar offsets are known along the coasts of the world, and wherever the dominant current is known from observation the offsets follow this law: *The current flows from the outer curve toward the inner one.* On account of the number of cases in which the offsets agree with the observed currents, it is pretty safe to conclude when offsets occur systematically in one direction that the dominant movement alongshore is in all probability from the curves which offset toward those which are offset.

FIGURE 2.—*Overlaps.*

Figure 2 shows typical overlaps. The right hand curve of the outer shoreline laps over the next succeeding curve of the outer shoreline. A curve which overlaps the succeeding one generally offsets it as well, though in places, as is shown in the lowest example in figure 2, the up-current curve may intersect the down-current one if extended far enough. This occurs where the factors of alongshore transportation are

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* H. Mohn: The North Ocean, Norwegian North Atlantic Expedition, 1876–'78, 2, xviii, p. 168, pl. xliii.

probably changing, and the down-current curve is really made up of two curves, and the up-current curve offsets the down-current one in each case. Typical examples of overlap occur as follows: Perdido bay, Florida (C. S., 187); Corpus Christi pass, Texas (C. S., 210); Townsends and Corsons inlets (New Jersey atlas, 17), and Fire Island inlet, Long island (C. S., 119).

The overlap is an intermediate form between the offset and the deflected stream. A graded series of examples might be given from simple offset through various combinations of overlap to a case of stream deflection without any offset.

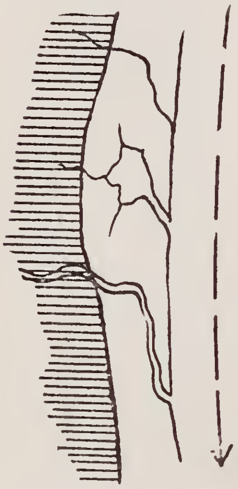

FIGURE 3.—*Stream Deflections.*

Along coasts which are formed of unconsolidated materials it is frequently observed that rivers, brooks, or tidal channels aim toward the sea for a certain distance and then turn and run along nearly parallel to the shoreline and finally empty to the right or the left of the point which would have been their direct course to the sea. The river's intention to reach the sea as quickly as possible is evidently not carried out where such deflection is seen. Some disturbing force has come in. There seems little doubt that this force is the current alongshore which has turned the outlet of the stream. Such has been the explanation of many authors.* Figure 3 shows the relation of current to deflection of streams.

The materials of which the foreland is constructed come from the mainland and the bottom on the up-current side, while on the down-current side they must be carried inshore from the point of the cusp or else built up from the bottom. This carrying back of sands from the point toward the mainland would frequently cause a hooked spit to form on the end of the cusp; therefore in this class of cusps a hook may be expected. Off the tip of the cusp irregular shifting shoals should occur, from which projections, like underwater spits, might be expected to extend in the direction in which the current flows along the edge of the shoal. Since these currents on either side of the cuspate foreland would be out of gear with each other, there would be set up between them small whirls of water which would tend to change the form of the shoals frequently.

TYPE.

With this deductive scheme in mind, let us turn to the maps of these capes (C. S., 11, 142, 145, 146, 147, 149, 150, 420, 421, 424, 425) and see

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* De la Beche: Geol. Notes, 1830, vol. ii, p. 11, pl. 1, figure 3; Reclus: La Terre, 1870, vol. i, p. 447; Sir A. Geikie: Text-book, 3d ed., p. 399.

what the form there shown tells us of the history of their formation. These charts cover such a large area and are executed in such detail that it is impossible to reproduce them satisfactorily for the purposes of this paper. The Coast Survey charts are accessible to many, and the facts which are here taken from them will be much better apprehended with the charts in hand.

In figure 4 is given a typical drawing of a current cuspate foreland. In it are combined those features of the three Carolina capes and cape Canaveral which the author deems important to show the method of growth. Former positions of the shorelines are indicated by the ridges of dunes built by the wind along the shore. Such former positions are beautifully indicated in Canaveral (C. S., 160, 161), where three or four successive positions of the outline of the cusp, each further to the left than the preceding, are delineated, besides many lines of aggradation in each position. Similar lines of growth are seen at cape Fear where the present right shoreline cuts off the eastern ends of the four dune ridges extending east-southeast from the light-house and curving sympathetically with the left shoreline. Cape San Blas, on the west coast of Florida (C. S., 183, 184), shows four stages on the right side and nine successive stages of aggradation on the left side. A more striking example of aggradation lines is seen in the cusp of Darsser cape in the Baltic (Germ., 61, 62, 63), where thirty-eight systematic and successive shorelines are indicated by dune ridges.


FIGURE 4.—*Type current Cuspate Foreland.*

The three criteria of form, offset, overlap, and stream deflection, by which we may recognize the direction of dominant movement alongshore are all seen along the Carolina coast, and are shown in the type drawing (figure 4). To make the point clearer each of the criteria will be considered separately and occurrences pointed out. The typical hooked spit and the shoals will be considered under later headings.

OFFSETS IN THE CAROLINAS.

Along the Carolina coast examples are numerous in which the right shore curve offsets the left. Among these the following cases will be mentioned from north to south: Oregon inlet, Hatteras inlet, Whalebone inlet, Beaufort entrance, Bogue inlet, New Topsail inlet, Cape Fear river, Shallotte inlet, and Murrells inlet. Bear inlet northeast of New river is the only prominent case where the left curve offsets, and in this region the overlap in New river inlet is from the right to the left.

The offsets are so common from the right to the left along the Carolina coast and so rarely does one occur where the left-hand curve is to the seaward of the right-hand curve that a dominant current moving from the right or north is indicated.

Along the Florida coast also the dominant overlap is from the right, as at Matanzas inlet (C. S., 159), Jupiter inlet (C. S., 164).

OVERLAPS IN THE CAROLINAS.

Examples along the Carolina coast from north to south are as follows: Stump inlet, Barren inlet, Bacon inlet, White Point swash, Singleton swash, Murrells inlet, and many smaller inlets. The right shore curve in each of these cases overlaps the left, which indicates that the transportation of material from the right to the left prevails over movement in the opposite direction. A few examples occur, as at New River inlet (C. S., 422), where the overlap is from the left, which shows some transportation from left to right. The right shore curve, however, at New river offsets the left, thus indicating that here there is movement also from the right. Storms from different directions and seasonal changes of winds occur along various shores, so one would expect to find indications of movement in opposite directions. The prevailing form of such a coast indicates the dominant current.

STREAM DEFLECTIONS IN THE CAROLINAS.

Streams are deflected to the left along the Carolina coast in the following places: Stump inlet, Cape Fear river, Lockwood Folly inlet, Bacon inlet, Shallotte inlet, Singleton swash, Murrells inlet, besides several little brooks and tidal inlets.

The deflection to the left of the Peedee River system is well shown on the geologic map of South Carolina, issued by the State Board of Agriculture in 1883.

There are a few examples of deflection to the right, particularly near New River and Little River inlets. These inlets occur in the bays between the cusps where the range of the tides is greater than at the capes themselves. Professor Shaler has pointed out* that this greater height in the bay would cause outflowing currents toward the horns of the bay. This action is indicated by the few cases of overlaps, offsets, and stream

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*Thirteenth Ann. Rep. U. S. Geological Survey, p. 180.

deflections to the right, all of which occur in the right-hand half of Onslow and Long bays. The dominant movement along the coast, however, from the indications of overlap, offset, and stream deflection, is from right to left, which accords with Mr Abbe's theory of backset eddies.

HOOKED SPIT OF LOOKOUT.

Cape Lookout is characterized by a spit projecting from the point of the cusp which has a recurving hook on its left side. This has been shown in the type drawing (figure 4). The curve of the right side of the spit is continuous with the curve of the right shore bar, with an offset from the right near the base of the hooked spit. On the opposite side of the spit the minute offsets are also from the right to the left. The offsets therefore indicate currents flowing in opposite directions upon the two sides of the spit, both moving from the right to the left. The form of the recurved hook is evidence for a current moving from the sea toward the land at this point on the left-hand side of the cusp, because for its extension material must be carried toward the point of the hook from some other locality, and since the hook curves in toward the land and has a smooth contour on the outside and an irregular one on the inside, transportation is inferred along the graded and not the ungraded path. The form of the Lookout recurved spit indicates a current from the land toward the sea on the right and one from the sea toward the land on the left of the cusp.

SHOALS OFF THE THREE CAPES.

Offshore from the Carolina cusps are shifting shoals which are dangerous to the mariner, and therefore are charted in detail by the Coast Survey. From the backset eddy theory one would expect shoals between currents moving out of gear, as any two adjacent backset eddies must necessarily revolve. This flow of water in opposite directions is indicated by the form of the shoals as given upon the charts. On the right side the spurs from the shoals point prevailingly seaward, while on the left they point landward, showing a systematically sympathetic accordance with the offsets on land. This is seen upon the charts of all three capes: Hatteras, Lookout, and Fear (C. S., 145, 147, 424). The shifting of these shoals is a well known fact, which is one of the reasons why this region off Hatteras is the one where more vessels have been lost than any other along our coast. This is shown by the records of the Hydrographic Office.*

THEORY CONFRONTED WITH FACT.

The above brief review of the facts of the Carolina coast as shown upon our maps is strongly indicative of an arrangement of alongshore

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*See Pilot Chart of the North Atlantic Ocean.

currents such as has been suggested above (page 404). A large array of facts point to a dominant movement from right to left along the coast, stronger in some places than in others, but dominantly in one direction. The few facts which appear to contradict the main hypothesis are explained by the secondary hypotheses of tidal currents or storm movements in the opposite direction. The forms of the cuspate points themselves suggest the backset eddies by their shoals, recurved hooks, offsets, overlaps, and stream deflections. The deductive and inductive study of this coast in the laboratory has suggested this explanation; its confirmation, extension, or rejection awaits the local observer in the field.

OTHER EXAMPLES.

Hatteras is a skeleton foreland; the outline is cuspate, but as yet the water body included by the offshore bar is not filled with sands blown by the winds and waste brought in by land and tidal streams. Lookout has a smaller water body and Fear still less water to fill, while Darsser cape in the Baltic is nearly all land. The foreland in this last case was built apparently by successive accretions, and probably never was in the outline stage of Hatteras.

In small water bodies, lakes, and tideless seas the winds would originate currents of smaller radius of curvature, which should in turn produce smaller cuspate forelands. The cuspate points in the Danish waters are probably such forelands. These are seen on the topographic maps of Denmark in the following localities: Roskilde fiord (Denm., Hilderöd), Söen Mellem Smalandene (Denm., Saxkjobing, Vordingborg), Limfjorden (Denm., Lögstör), on Langeland and the islands to the west (Denm., Svendborg, Nakskav, Gulstav, Faaborg), and in other localities along the Danish and German coasts.

Del Faro point, on the northeast of Sicily, projects between the current in the straits of Messina and the eddy of the Tyrrhene sea (Ital., 254).

The Bonneville cuspate forelands belong in this first class, which includes those cusps formed by wind-made currents, although in size and contour they more nearly resemble the tidal cusps of the next class than they do the Carolina forelands. They are proportional to the currents which existed on the old lake and are similar in size and outline to the Danish cusps. Professor Russell also reports V-bars in the fossil shores of lake Lahontan.* These cusps seem to have been built upward as the waters of the lakes rose, but the water level never remained constant long enough for the lagoons to become filled forming solid forelands, since Mr Gilbert reports only a partial silting up.†

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* Monograph XI., U. S. Geological Survey, p. 93.

† Loc. cit., p. 121, pl. xviii.

The type of current cuspate forelands has been given as the Carolina case where the cuspate form is so marked and well known. The hypothesis of backset eddies from the Gulf stream, here presented as the mode of origin, may not be so well known and may require confirmatory proof. This hypothesis is not given as the only one for the origin of all current cuspate forelands, though it is the only one here considered *in extenso*. Two other possible combinations of currents have been pointed out, and several different causes may originate the currents in different places.

TIDAL CUSPS.

LOCATION AND DESCRIPTION.

In regions of drowned valleys, long inlets, or narrow sounds, where the two opposite shorelines are roughly parallel to each other, cuspate deposits of sand frequently occur when shore evolution has reached an adolescent stage of development and transportation alongshore has begun.

These forelands usually project from one-quarter to three-quarters of a mile into the sea and vary in breadth between the same limits. In some cases the cusps are long and narrow, while in others they are short and broad. Frequently they inclose, more or less completely, lagoons but in some instances there is no included water body or if there was one it has become filled. The curve of the two outer edges of these deposits is concave toward the water and is a continuation of the curve at the base of a shore cliff. These two concave curves intersect in a marked cusp which is sometimes typically pointed, though in other cases the tip is rounded. The axis of these forelands projects approximately at right angles to the shoreline and also at right angles to the general direction of the tidal currents in the inlets.

TYPE.

West point, north of Seattle, Washington (figure 5), will be taken as the type, and, after giving its description and discussing the method of its formation, others differing in details of form will be considered. Magnolia bluff, two miles northwest of the city of Seattle, has a gently swinging curve doubtless quite satisfactory to the current here prevailing. This curve continued forms the right boundary of the West point cusp. The curve on the left side of the foreland is in like manner a continuation of the curve of another cliff (C. S., 658; G. S., Seattle). On the inside of the cusp there is a faint cliff where the coast was nipped after the initial drowning. The central lagoon is nearly all converted into marsh, a small tidal inlet remaining on the left side with a few small ramifying branches.

The cusp is very perfectly formed by the intersection of the two curves in a sharp point.

Plate 18 (facing page 399) represents a cusp in Narragansett bay which is nearly as typical in form and position as West point. Sand point projects from the eastern side of Prudence island (C. S., 353) into a channel less than two miles broad and from 10 to 17 fathoms deep, 5½ fathoms off the point of the foreland. This cusp is smaller than the average tidal cusp and it shows no included lagoon or marsh. Mr J. B. Woodworth, for whom the photograph was taken, says that the ice in winter overrides this cusp and thus any indications of embryonic form would be obliterated. The secondary cusp on the left side of the foreland appears to be due to the collection of sand about rocks or piles. The view is taken from the cliff south of the foreland looking northeast.*

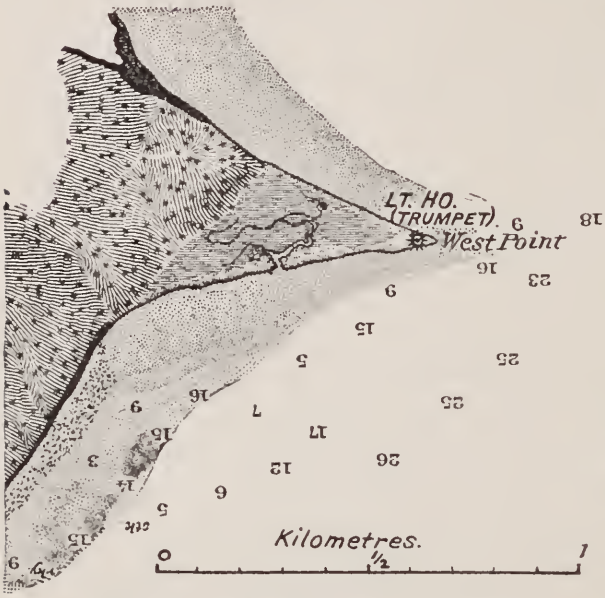

FIGURE 5.—*Type tidal Cuspate Foreland.*

A profile has been drawn from another typical cusp, point Wilson (C. S., 6405), north of Port Townsend, Washington. This drawing (figure 6)

FIGURE 6.—*Profile tidal Cusp.*

The ratio of the vertical to the horizontal scale is 2 to 1.

shows the relation of the foreland to the older mainland. The broken line indicates the probable initial form of the land following the depression which inaugurated the present cycle of shore development. The "foreland" quality of the cusp is here clearly seen. It is constructed by transportation and accumulation in front of the nipped oldland. Although plotted from the soundings and contours about point Wilson, this figure will serve as a general profile of all the cusps of this class.

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*Taken by Mr P. P. Sharples and published by permission of the Director of the United States Geological Survey.

Where the initial slopes were less steep, less contrast is seen between the oldland and the foreland.

TIDAL HYPOTHESIS.

Before considering other cusps which differ somewhat from West point, let us look for a moment at what might be expected to result in narrow channels with sides nearly parallel. Waves would attack this inner shoreline to a greater or less extent at all points. When adolescence is reached in the process of shore evolution and waste is supplied faster than it can all be carried offshore, it will be transported and deposited somewhere. What is the agent of transportation? Where should one expect to find the waste deposited? It has already been pointed out that the great system of ocean eddy currents is not able to affect the inner as it does the outer shoreline. Local winds must produce small currents proportional to the size of the water bodies, but these will be so weak in narrow channels that their effects will be lost in those of even moderately strong tidal currents. Thus it seems safe to conclude that the probable agent of transportation in such channels is the tidal ebb and flow.

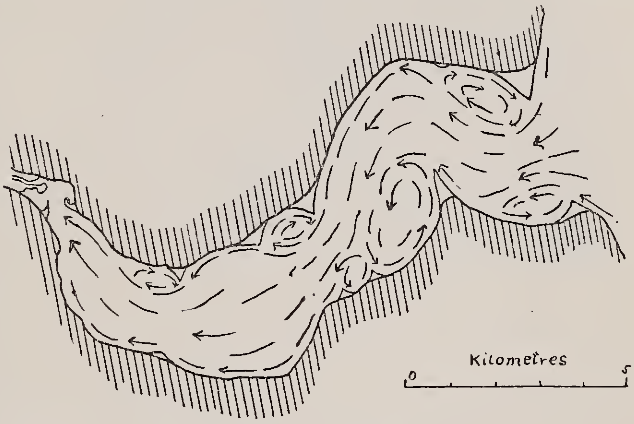

FIGURE 7.—*Ideal Scheme of tidal Inflow, Port Discovery, Washington.*

An ideal scheme of inflowing tide with the eddies which would probably accompany it is given in figure 7. Where the movement is least in the triangles of more or less dead water between the several members of the circulatory system the deposition would take place. In the majority of places the outflowing tide would reverse the direction of flow and transportation of shore waste; therefore the combined action of ebb and flow would shape the tidal foreland so that its central axis would be at right angles to the general direction of tidal flow.

The cuspate forelands which are mentioned under the three following heads are arranged in three stages of progressive development, the V-bar stage, the lagoon-marsh stage, and the filled stage.

V-BAR STAGE.

A much younger stage than that of West point is seen on the same sheet at Meadow point. Here the bars surround a relatively large lagoon which apparently has hardly begun to fill. The form of this bar is what Mr Gilbert has called V-shaped.*

Various examples on the east coast of Port Discovery (C. S., 648) show V-shaped bars inclosing lagoons. The greater number of forelands in this bay have their greater extension alongshore. Beckett point, however, has its length normally at right angles to the shoreline.

At point Monroe, near Port Madison, Washington (C. S., 663), a looped bar incloses a lagoon somewhat similar to those just mentioned (figure 8). The shore drift is here all from the left, and the curve of the bar is convex seaward. At point Jefferson, further north, on the same sheet there is another convex bar inclosing a lagoon where the drift has been from the left, as shown by the continuation of the cliff curve in the bar. These two examples do not give the typical cuspate form.

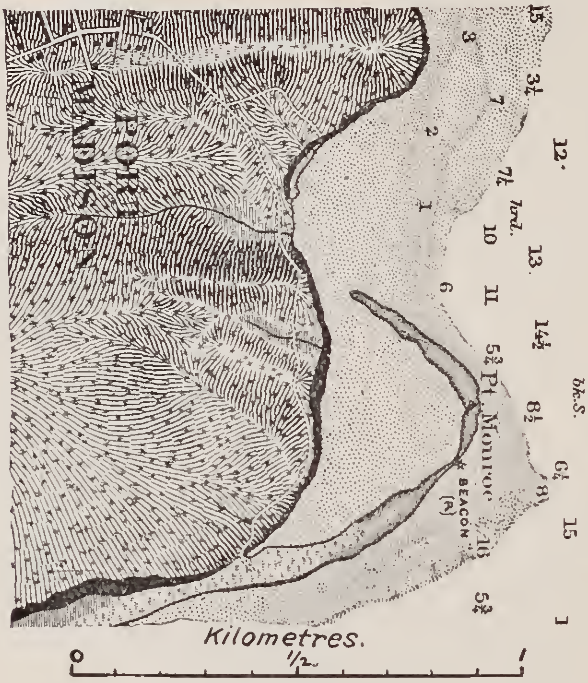

FIGURE 8. – *V-bar Stage.*

LAGOON-MARSH STAGE.

Various stages of lagoon filling are shown on the Port Townsend sheet (C. S., 647; last edition, 6405). Walan point foreland has considerable area of lagoon and still maintains open connection with Port Townsend. At point Hudson there remains an unfilled lagoon but its connection with the sea is lost. At point Wilson a small lagoon now exists, while at Kala point the lagoon is practically converted into a marsh. On the foreland at Marrowstone point the sand dunes have almost obliterated the marsh.

On this same Port Townsend sheet the rounding of the point of the cusp may be studied. At Port Wilson the concave curves intersect in a slightly rounded cusp, while at Kala point the cusp is more blunt, and Walan point is decidedly rounded. The curves at point Hudson have a long radius so the sides of the cusp are nearly straight, and since they meet nearly at right angles, the foreland has a broad, flattened appear-

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* Loc. cit., pp. 57, 58.

ance. The curve on the right side of Marrowstone point changes from a concave to a convex form so that it gives that side of this foreland a snubbed look.

Sand point, projecting into Popof strait, Alaska (C. S., 8891), is a fairly typical example of a cuspate foreland with inclosed lagoon. The point is here somewhat blunted, more on the southern than on the northern side. This foreland as mapped is very evidently a piece of made land built forward in the process of shore development.

A typical example is seen in New Dungeness harbor, Washington (C. S., 646), where inside of the beautiful hooked spit forming the harbor the foreland projects with a very sharp point.

Gaspee point (figure 9) in Narragansett bay (C. S., 3047) may be taken as a typical example of this lagoon-marsh stage.

A rounded cusp with completely inclosed lagoon occurs near the mouth of Hörup bay (Germ., 24; Denm., Faaborg). Upon the same sheet there is a typically sharp pointed cusp projecting from the north end of Ärö island. This projects at right angles to the general shoreline, but the belt of water is here so wide that the wind-made currents probably have as much controlling influence as the tidal, possibly more.

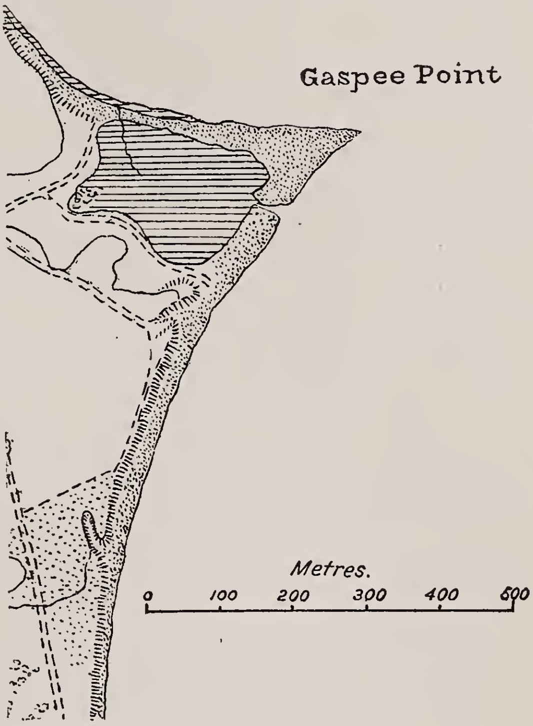

FIGURE 9.—*Lagoon-marsh Stage.*

FILLED STAGE.

Dunge Ness point, on Romney marsh, England, is a cuspate projection into the English channel (Eng., 4). The direction of transportation of detritus is from the west around the point.*

This foreland seems, on account of the large marsh areas included, to have passed through a V-bar stage, but the aggradation lines of growth at the point, which has changed its position since records have been kept, suggest that the second method of growth, mentioned below, has succeeded the first at the point.

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* W. Topley: Geol. of the Weald, 1875, pp. 211, 303; F. Drew: Romney Marsh, Mem. Geol. Sur., Eng. and Wales, 1864.

In the eastern entrance to Magellan strait, South America, is one of the largest known forelands of this class. Westward from cape Virgins and south of a nipped cliff 100 to 300 feet in height projects from 5 to 6 miles a second Dungeness, named by some British seaman in recognition of a form similar to that of the great English sand cusp (H. O., 443, profile in view *A*).

Sandy point, Magellan strait, South America (H. O., 450*a*), is another example.

Alice point, on the bottom of the foot of the Italian boot, is a foreland which shows no included marsh. Its axis, if projected across the gulf of Taranto, would touch the extremity of the heel, as if its existence showed the attempt of the sea to close the gulf (Ital., 231).

South of Rettin there is a somewhat irregular cusp (Germ., 84).

A cusp projects into Der Bodden from the southeastern point of Rügen island (Germ., 89).

There are several cusps inside of Frische and Kurische bars (Germ., 3, 8, 15, 16, 29, 48, 49, 71, 72).

In Vejle fiord (Denm., Fredericia) there are several cuspate projections, often called "Hage" or hook, whose form and position indicate eddies in the tidal in and out flow.

At the mouth of the Elbe river, west of Cuxhaven, is a low projecting point which seems to be a foreland (Germ., 110).

Two broad, completely filled cuspate forelands occur in the Kieler and Eckernförder bays respectively (Germ., 58). Friedrichsort is built upon the former, while the latter lies six kilometers east of Eckenförde.

METHODS OF GROWTH.

It would seem from inspection of the maps that it was the more common thing to inclose lagoons, though in some places the growth has evidently begun at the mainland and progressed outward. In False Dungeness harbor, or Port Angeles, some of these cuspate deposits are seen which do not appear to have ever inclosed any lagoons (C. S., 646; last edition, 6303). Three of the cusps on the inside of the Coatue spit, Nantucket, have no lagoons; but as the other two have and since they are nearer the end of the spit and hence probably later formed it is quite likely that the earlier formed forelands also began with lagoons (C. S., 111, 343; G. S., Nantucket, Mass.).

Professor Shaler has ascribed these Coatue cusps to tidal whirlpools. He says:

> "From a superficial inspection it appears that the tidal waves are thrown into a series of whirlpools, which excavate the shores between these salients and accumulate the sand on the spits." *

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* Bull. U. S. Geol. Survey, no. 53, 1889, p. 13.

Among these filled cusps are included doubtless those which have passed through the V-bar stage as well as those which have grown by gradual outbuilding, since from present knowledge it is impossible to separate the two groups. With better maps and descriptions of the cusps a later classification will make closer distinctions.

THEORY CONFRONTED WITH FACT.

After this general survey of the varying forms of cuspate forelands selected from the many examples in the narrow water bodies of the world, the following generalization may be made: However varied the form resulting from the local conditions, tides, relief of oldland, etcetera, the axis of a line drawn from the point of the cusp through the center of the foreland is always at right angles to the general direction of flow of the tidal currents.

Where there are strong tides, as in Puget sound, Chesapeake bay, and Narragansett bay, there are numerous and typical cuspate forelands; while in Albemarle sound the range of tides is less than one foot, and here few sandy points of a cuspate form occur.

Thus the facts of observation seem to correspond with the principal requirement of the theory. Studies of the existing currents in regions where these forelands are found are now needed to further test the tidal hypothesis. From present knowledge this seems to be the best working hypothesis.

Two methods of growth are suggested. In one the outline of the foreland is early given by a V-bar, and later this inclosed lagoon is progressively filled. In the other the foreland grows by successive additions to the mainland. The first appears to be by far the larger class, though examples of the latter are liable to be confused with the filled stage ot the first class.

Between the narrow channels and the open sea there are all gradations in size of water bodies, so we should expect to find forelands built by combination in different proportions of tidal and wind currents. Such cases have been referred to above in Del Faro point, Ärö island cusp, and Alice point.

DELTA CUSPS.

INTRODUCTORY STATEMENT.

Rivers in wandering across their alluvial plains often produce along their banks small cuspate points between whirling eddies, which are located along river banks as the tidal cusps are along inland channels. These could hardly be grouped as a class of forelands as the word has been used, but the rivers in entering the sea often do aid in the construction of cuspate projections from the older mainland, and this class of forelands will now be considered.

RIVER VERSUS CURRENT.

When a river empties into the sea a contest ensues between it and the currents, except where the sea is at work upon an offshore bar and the river mouths in a protected lagoon. The river transports waste to sea-level, the currents transport it beyond wave attack or below wave-base. At the shore therefore the river intention and the sea intention are opposed to each other. The river tries to build forward its delta, while the sea attempts to cut into the land. If the river intention is successful a lobate delta results. If the sea carries out its desire no delta is constructed, the complete satisfaction of the sea being shown where the river is blocked by the beach, the water having to filter through the sand, as is the case at Oceanside, California. A great variety of intermediate forms of deltas occur, which are determined by the arrangement and the ratio between river and sea activity. One where both agents are effective is the cuspate delta.

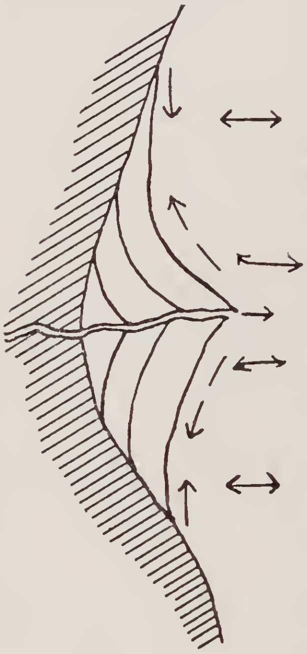

FIGURE 10.—*Ideal Stages of Delta Growth, with dominant on and off shore Currents.*

THEORY OF FORMATION.

Three hypotheses for the formation of cuspate deltas will be here presented. The first (figure 10) is where the river mouths in a locality where the dominant sea action is on and off shore. The current flowing toward the land will flow to the right and left of the mouth of the stream, carrying the river detritus toward the mainland and building out the foreland. The outflowing current will doubtless carry some material back from the land, but according to this theory of growth the foreland is built up mainly from the land waste brought down by the river and from bottom detritus brought inshore by the currents.

The second hypothesis is where the dominant action is alongshore. As indicated in figure 11, the current is from the right. In the earlier stages of this method of growth the alongshore current, if relatively stronger than the river current, will curve around the mouth of the river and give the delta a rounded outline. As the delta grows forward it becomes more difficult for the alongshore current to bend around the point of the delta, and finally it is broken into two eddies, as shown in the outside current lines in figure 12. A rounded delta may thus become a cuspate one. If the ratio between river and sea increases in favor of alongshore action a cuspate delta may be changed to a rounded one.

Included marsh areas are drawn in this type because where a dominant movement alongshore is indicated on the maps such areas usually occur. They do not necessarily result from this hypothesis of growth, and may occur in any delta where the advance has been by leaps.

The third method of formation is where two currents move alongshore, one from the right and the other from the left, toward the mouth of the stream. The river may act in this case as the projection of the land at the beginning of a new cycle was supposed to do in starting the growth of a current cuspate foreland (page 403).

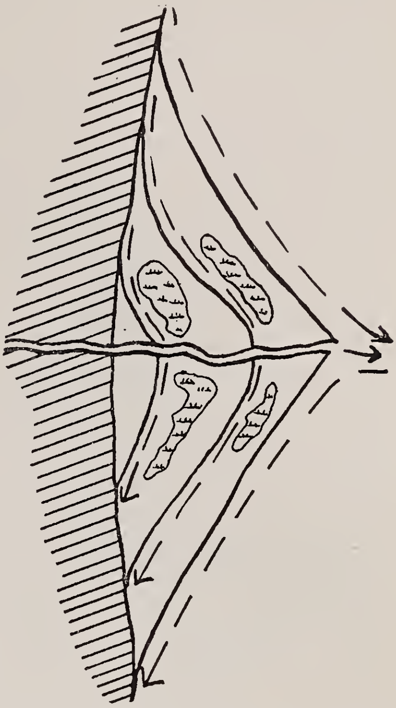

FIGURE 11.—*Ideal Stages of Delta Growth with dominant alongshore Current.*

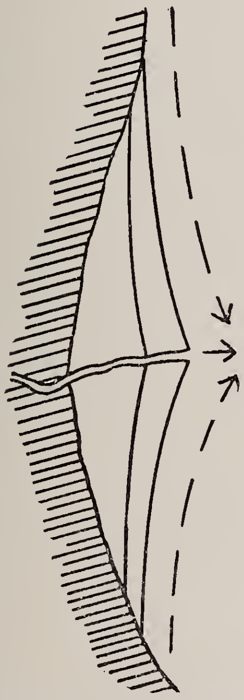

FIGURE 12.—*Ideal Stages of Delta Growth with two alongshore Currents toward Delta.*

The three methods of growth can doubtless be easily distinguished upon the ground. It is not so easy upon the maps, for the main indication as to current upon the delta foreland is the deflection of small streams. Such streams often do not exist. Offsets and overlaps are not common upon delta forelands. If there is a dominant current along a coast a delta occurring upon it may with great probability be referred to the second method of growth. Like so many other things in this world, this is wholly a question of ratios, and in any given delta there will be some on and off shore action and some alongshore action.

TYPE.

The typical example of a cuspate delta is given in figure 13. The two gently swinging shore curves concave seaward with their dune-lined beaches are the work of the sea. At the point of intersection of these two curves the river mouths. The form of the land shows that if it were not for the river there would not be any cusp here, as there is no projecting point in the oldland to cause eddies in the currents. The evidence from the turning of the mouths of the small streams both to right and left indicates that the direction of current motion alongshore is probably sometimes in one direction and sometimes in the reverse. The smaller streams on each side of the river mouth are deflected away from the point of the cusp, indicating that the delta mass divided an on-shore current and turned it to the right and left, carrying the river sediment from the river along the shore. Further from the river, both on the right and left sides, there are streams deflected toward the mouth of the main stream. There is here evidently no dominant movement in either direction alongshore.

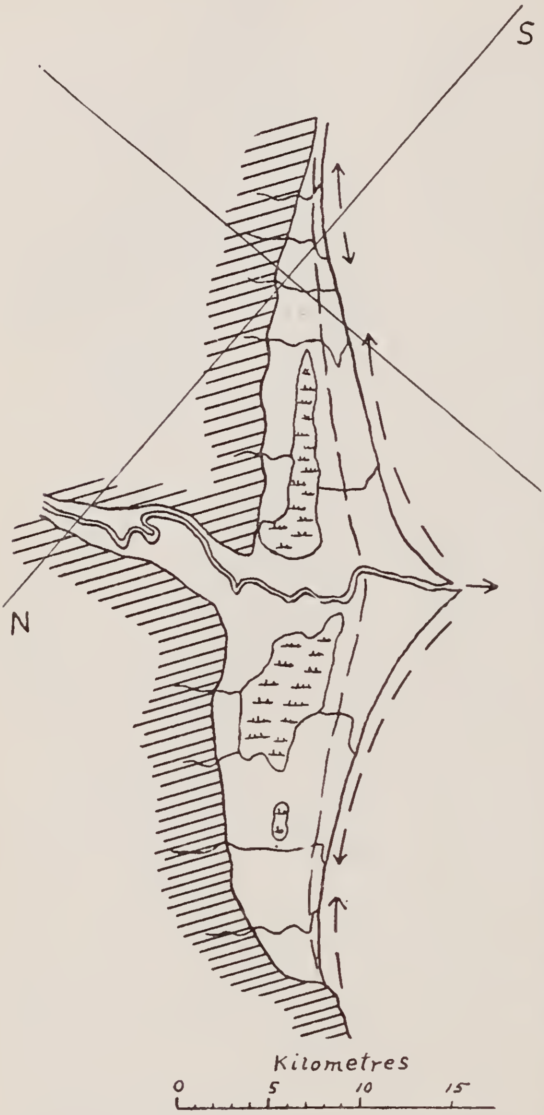

FIGURE 13.—*Type delta Cuspate Foreland.*

A former stage of the delta is indicated by the ridge of geologically older material, which is represented in the figure by the broken line. This earlier stage of the delta front is seen to have a rounded outline. This suggests that formerly there was a dominant movement alongshore. Back of this former shoreline are seen ares of marsh, filled lagoons, or lowland behind the old beach. Since this leap from some still earlier position of the shoreline, the forward growth seems to have been gradual, for no long slashes of swamp are shown. From map inspection this delta cannot be definitely referred to either of these hypotheses of origin, for it combines features of both the first and the second.

This type is the Tiber (Ital., 149; Carta Geologica della Campagna Romana, Roma, 1888). It has been turned from the usually desirable north and south orientation parallel to the sides of the page in order to have all the figures in this paper stand with the water on the right and the land on the left.

OTHER CUSPATE DELTAS.

A delta less cuspate than the Tiber is the Tagliamento (Austr., 22, viii, ix; 23, viii, ix), which shows very prettily three stages of growth, indicated by lines of villages on higher ground, with intervening marsh areas.

The Angitola delta, Italy (Ital., 241), is apparently an embryonic stage of the method of formation illustrated in figure 11. It extends a small cuspate point beyond the curve of the bar closing the bay, as if the stream crossing the bar was relatively strong enough to divide the alongshore current. It has been found impossible to pick out from the other examples of cuspate deltas given below any which were later stages of the Angitola type. The maps give little more than the form of the latest stage of development. The progressive series of forms should be studied on the ground in order to see what was the embryonic condition. This study is analogous with what is done by the paleontologist when he peels off the outer shell of an Ammonite in order to discover its embryonic form.

In both the Biferno (Ital., 155) and the Ofanto rivers (Ital., 165) the deflections indicate a current from the right at present, though formerly the deflection was in the opposite direction.

In the two following examples of delta forelands, Volturno (Ital., 171, 172, 184) and Ombrone (Ital., 127, 128, 135), the streams are deflected in both directions, thus indicating no dominant current alongshore.

The current is probably from the left, in front of Alento delta (Ital., 141) and from the right at Neto delta (Ital., 238).

In the Volstrap at Saeby (Denm., Frederikshavn) the southward deflection of the mouth indicates a prevailing current from the right.

The Danzig mouth of the Vistula (Germ., 70) shows deflection to the right.

Kolberg is built on the cuspate delta of the Persante (Germ., 93). The evidence along this coast is for a current from the right.

Punta Arenas, a Chilean settlement, South America, is built on a foreland made by combined action of river and sea (H. O., 450*a*). Deflection is to the left.

Many of the discharge sluices emptying into the Zuider Zee have built cuspate deltas, and though aided by artificial means the form is so typically cuspate that they are included in this category (Holl., 15, 16, 21, 26, 27, 32).

CUSPS FROM ISLAND-TYING.

A characteristic feature of shore development of a drowned region during adolescence is the tying of islands to each other and the mainland.

Upon the coast of Italy where island-tying in its various stages is beautifully shown such a bar is called a tombolo. For convenience in distinguishing island-tying bars from those of other kinds, the writer proposes to call every bar of this kind a *tombolo*, giving an English plural tombolos. In the early stages of the growth of a tombolo a condition occurs similar to what is shown in figure 14, where two cuspate points project toward each other, the one from the island and the other from the mainland. Either cusp may occur without the other, according to where transportation first begins. A case like the figure is seen on Aebelo island in Grand Belt strait (Denm., Bogense). Here the cusp points toward another cusp projecting from a smaller island between Aebelo and the mainland.

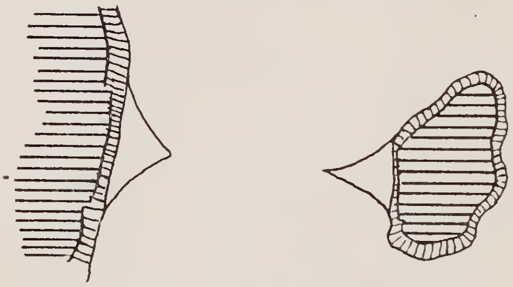

FIGURE 14 —*Tombolo Cusps.*

Another example is Spectacle island, in Boston harbor (C. S., 337), where the "nose-piece" of the spectacles consists of two cusps almost joined.

From Tuno island (Denm., Samsö) there projects toward Samsö island a lanceolate cusp whose position indicates that it was formed by in and out flowing tides or by two currents running on either side of Tuno island toward the larger land area.

After an island has become land-tied by one tombolo or by two inclosing a lagoon, which in time is converted into marsh, it continues to be consumed by the sea upon its outer side. There will come a time when the island is almost or quite gone (figure 15) and the tombolo construction will remain for a short time in a form like that of the cuspate forelands described above. The northern point of Block island (C. S., 356) seems to be of this origin. There is the following tradition of Sandy point, Block island: "On the extremity of the point was anciently a peninsula called the Hummuck. It was an elevation of land on which small trees and bushes grew, and at low tide was reached on foot. The old inhabitants now speak of having gathered wild plums there. It was washed away long ago."*

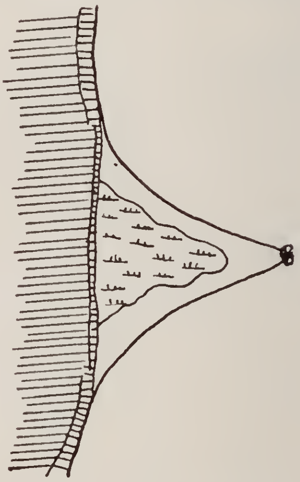

FIGURE 15.—*Island Cusps.*

An example where the island is not so completely eroded but in which the cuspate form is less typical is Colchester point in lake Champlain (G. S., Plattsburg, N. Y.).

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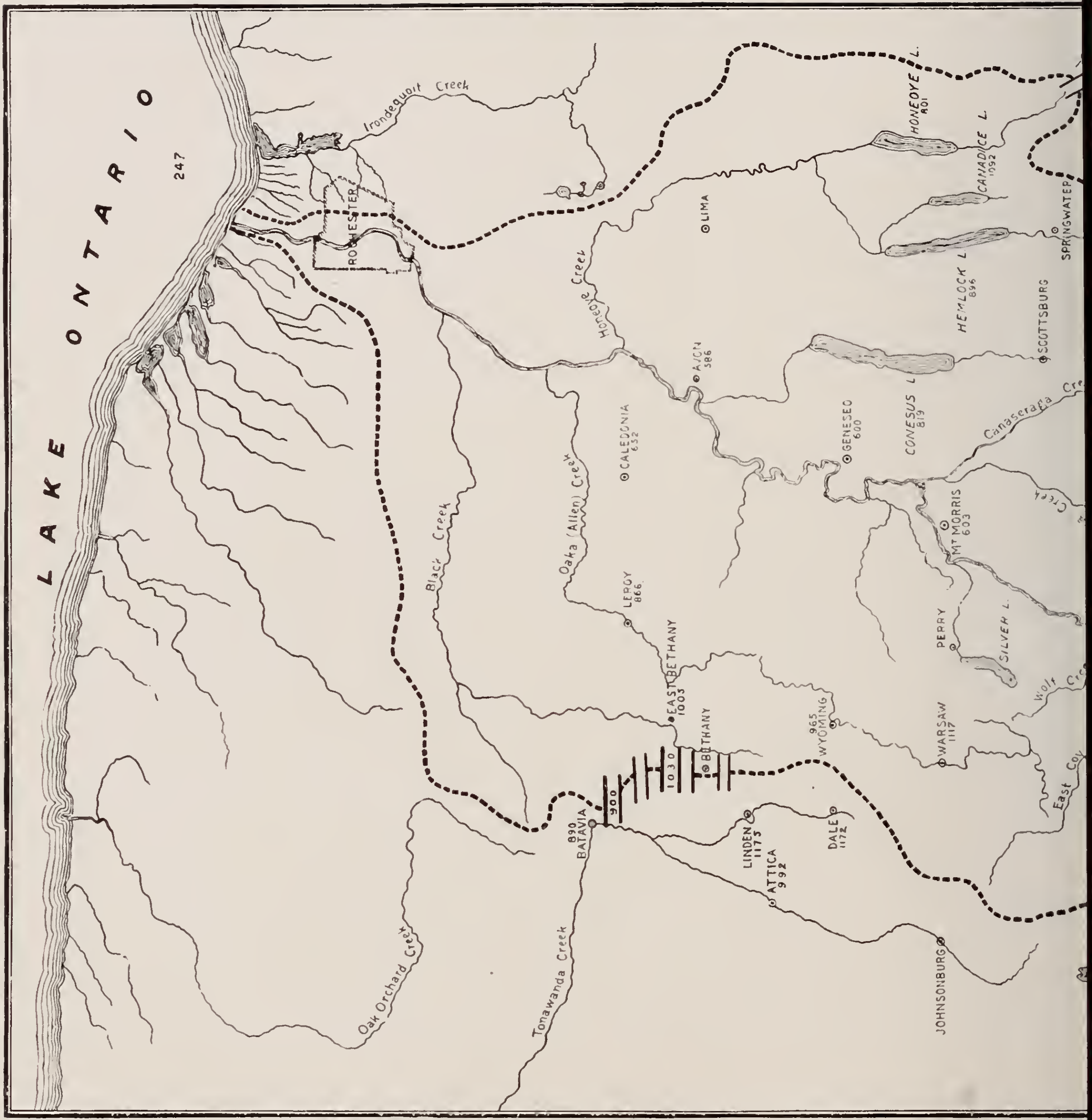
*S. T. Livermore; History of Block Island, 1877, p. 175.



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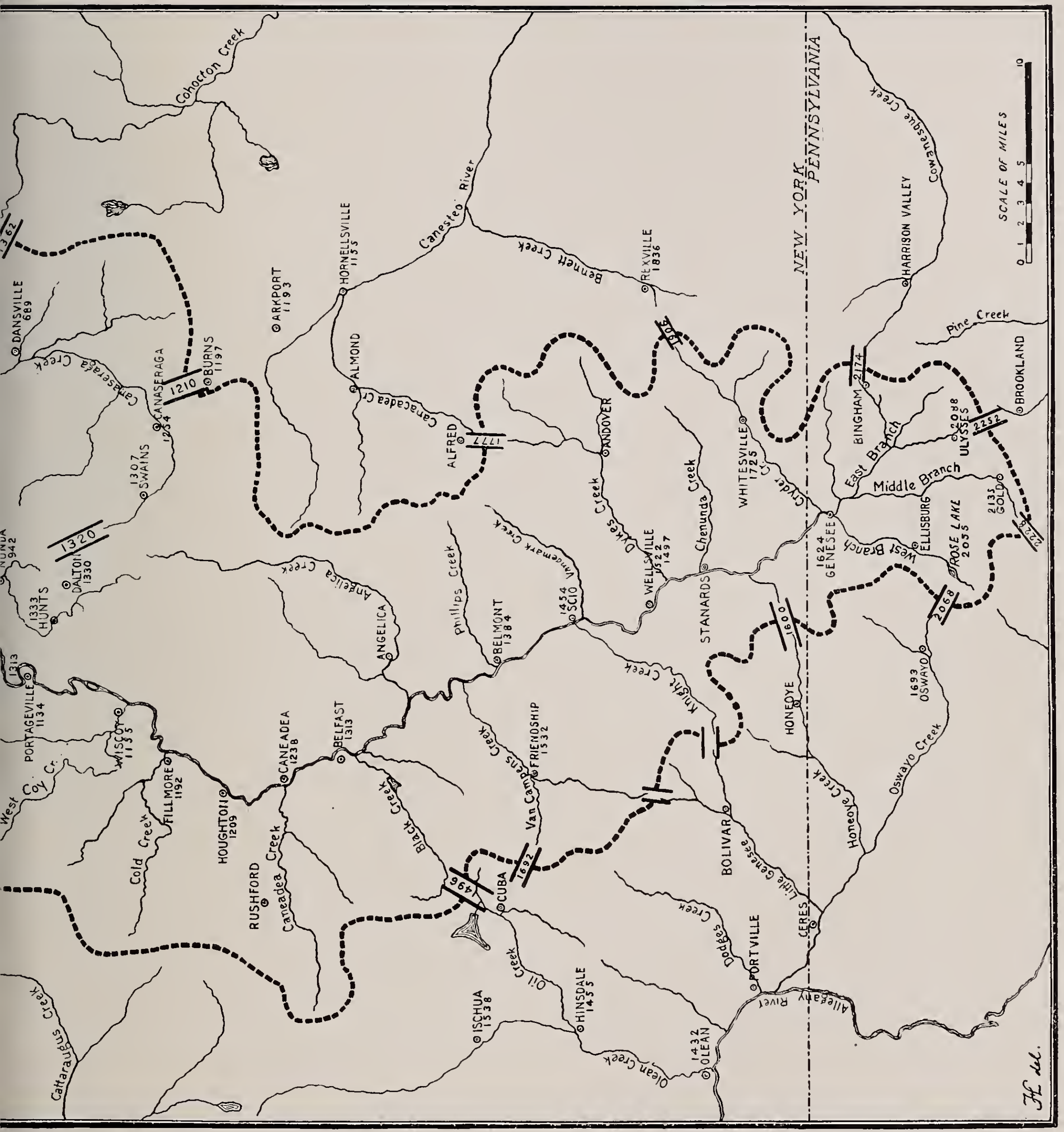

ENESEE VALLEY.

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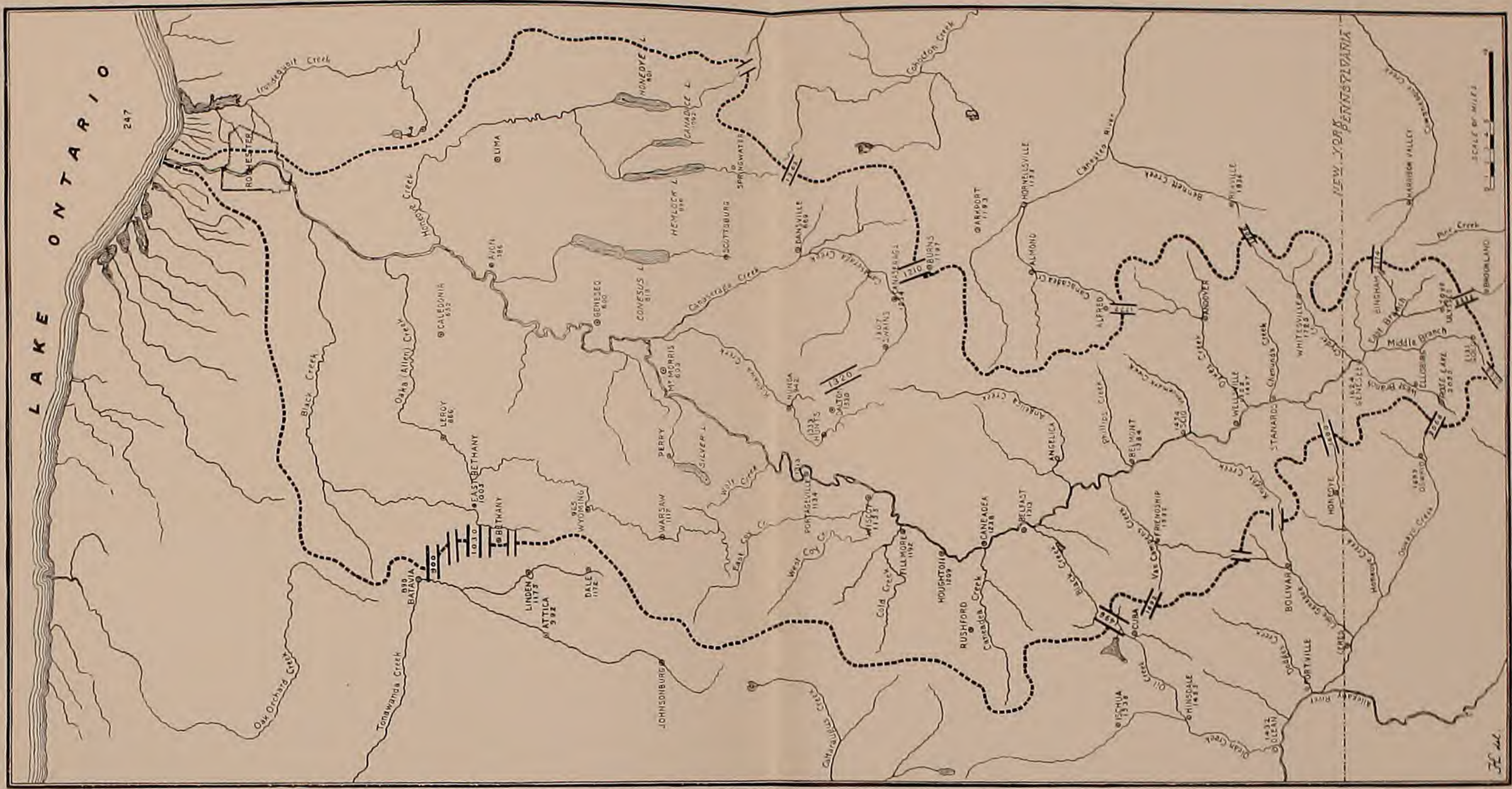

HYDROGRAPHY OF THE GENESEE VALLEY.

Water-parting shown by heavy broken line.
Glacial lake outlets indicated by bars transverse to the water-parting.
Figures indicate altitude above mean tide.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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GLACIAL GENESEE LAKES

BY H. L. FAIRCHILD

(Read before the Society August 27, 1895)

CONTENTS

INTRODUCTION.

The study of the lacustrine history of the Genesee valley was undertaken in continuation of the work upon the glacial lakes in western New York * and with no expectation of making it the subject of a separate paper. The history is found, however, to be of remarkable and romantic character. The glacial waters alternately flowed to the gulf of Mexico and to the Atlantic ocean direct. Five great river systems received the overflow at different periods, namely, Ohio-Mississippi, Susquehanna, Illinois-Mississippi, Hudson, and Saint Lawrence.

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* Glacial Lakes of western New York: H. L. Fairchild. Bull. Geol. Soc. Am., vol. 6, 1895, pp 353–374.

The phenomena are complex and singularly interesting, and the determination of the several water-levels, involving the facts concerning the nature and sequence of the geologic events, reveal a fine problem in glacial geology which is thought to have been solved in its general features. A vast body of interesting details remains unstudied.

The work upon the region was done in the late autumn of 1894 and the summer of 1895. The data relating to the water-planes were collected without reference to their bearing, and with only indefinite idea or theory as to the corresponding outlets. The latter, indeed, were not wholly known and the correlation of the planes of the static waters with the several outlets has been completed since leaving the field.

The largest part of the work has been the determination of altitudes.* With no topographic map of the region, the railroad " levels " have been the only data available. While these may, in some cases, have an error of perhaps a few feet, it can never be sufficient to compromise the conclusions of the paper.

THE PRESENT GENESEE VALLEY.

HYDROGRAPHY AND TOPOGRAPHY.

The general hydrographic features of the area are so well shown by the accompanying map † (plate 19) that much verbal description can be omitted.

Among the rivers of New York the Genesee is remarkable for its length, direction of flow and amount of fall. From its sources in Potter county, Pennsylvania, to its mouth at lake Ontario, the distance in a right line on the map is 100 miles. The total length of the river in all its windings is at least one-half more.

The altitude of the cols in which the east and middle branches of the river head is over 2,200 feet above tide, while the enclosing tableland is one or two hundred feet higher; so the fall in the stream from its origin to lake Ontario (247 feet above tide) is about 2,000 feet. The inclination of the basin at the time of the ice-retreat was probably a few hundred

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* The writer would here express his gratitude to the many persons who by personal assistance and various courtesies have aided in the work. Especial thanks are due to the following gentlemen: Professor J. P. Slocum, Angelica; Professor A. J. Glennie, Bolivar; Mr George W. Pierce, Canisteo, engineer N. Y. and P. railroad; Mr M. S. Blair, Hornellsville, superintendent C. N. Y. and W. railroad Mr C. R. Neher, Rochester, division engineer W. N. Y. and P. railroad; Mr George A. Thompson, Rochester, and Mr H. E. Gilpin, Hornellsville, division superintendents of the Erie railroad.

† The basis of this map is the map accompanying the report of Mr John Bogart, state engineer and surveyor, on the Supply of Water from the Genesee River to the Erie Canal, 1890.

feet more, as the Ontario basin was considerably lower than it is at present.

Proportionate to its length the hydrographic area is narrow, being only 40 miles wide at the broadest place, on the parallel of Silver lake. Toward its northern terminus the valley narrows rapidly until for some miles from the lake the river has no tributaries of consequence, and the valley is merely the recent or postglacial ravine.

The total area drained by the Genesee is estimated by Mr Bogart at 2,445 square miles.

The form and dimensions of the valleys of both the river and its tributaries indicate, in the main, a mature drainage system. The old valleys, where not drift-filled, are comparatively open, broad and with gentle grade. The dendritic form of the drainage in the middle and upper sections of the basin, which would be much emphasized by indicating on the map the smaller streams, is an evidence that glaciation has not there greatly changed the ancient drainage. The important exceptions in the lower part of the basin will be described below.

The altitudes of the area are sufficiently indicated upon the map. The figures given in connection with the names of towns and villages are the height of the rail in front of the railroad stations, referred to ocean level.

DRIFT DEPOSITS.

The amount of glacial drift still remaining in the valleys is very great, probably surpassing in amount any similar deposits in western New York. This is surprising when we consider the erosive power of the present streams and the vast amount of drift that has certainly been removed. In some localities the river valley is sufficiently open, either by original absence of drift or by subsequent clearing, to permit a view of its original form, but generally huge ridges or hills of drift obstruct the view. In at least one instance the old river valley was so completely closed by the drift that the river has been diverted into a new channel, and in the cases of side valleys and tributary streams this diversion of drainage has been more frequent.

In most sections the drift has been partially terraced or leveled by the successive work of lakes and streams. The subsequent erosive atmospheric agencies have, however, destroyed the water-planes in more or less degree.

The composition of the drift deposits has not been determined to any important extent. Casual observations suggest that much is ground morainal or till accumulation, but that probably the greater mass is water-laid drift.

The origin of the drift material has not been carefully studied. The great bulk in any section seems to have been derived from the terranes contiguous on the north, but some percentage is far-traveled material, as Medina, or even hypogene waste from the crystalline terranes, north and northeast.

The ancient Genesee Valley.

POSTGLACIAL CHANNELS OF THE GENESEE.

Throughout the greater part of its course the river flows in its old valley. It may be said in general that the ancient valley is the present valley from the source to Portageville. Some unimportant divergences of the river from its preglacial bed probably occur above Portageville. The few, but very important, diversions below Portageville are found where the river has been compelled by drift dams to abandon its former valley and to cut new rock channels. To trace the old buried valleys will require a brief description of the new rock channels.

The postglacial channels of the river are really only two—one from Portageville to Mount Morris, and the other from Rochester to lake Ontario. In both cases these have produced fine canyons and noted cataracts.

At Portageville an impregnable barrier of drift was left by the glacier, blocking the whole valley, which here was probably two miles wide. The local morainal lake thus formed by the drift dam found its outlet over the western rock-wall of the ancient valley, and the downcutting through the Portage shales has resulted in the famous Portage ravine and falls.

Between the Portage ravine and the rock-cutting at Mount Morris the river, while in a channel new to itself, does not occupy a postglacial excavation, but the narrow preglacial valley of some tributary of the ancient river. In curving from one side to the other of this narrow valley the river has undercut the rock-wall in several places, producing vertical exposures of the strata. Near Mount Morris this valley also was closed by morainic drift and another local morainal lake was formed in the river, which we will call Saint Helena lake, lower and smaller than the Portageville morainal lake. The outlet was cut down through the Hamilton shales, producing the ravine known as the "high banks." By erecting an artificial dam in the narrow channel above Mount Morris it is proposed to impound the Genesee water in this valley, thus partially restoring the Saint Helena lake, and so create a storage reservoir for equilizing and controlling the flow of the lower river.

At Rochester the river has again departed from its old channel and has excavated a canyon in the Niagara formation, with three cataracts, rivaling the similar phenomena at Portage.

POSTGLACIAL CHANNELS OF TRIBUTARY STREAMS.

The larger streams tributary to the Genesee river generally lie in their ancient valleys. This statement needs qualification chiefly as relates to the lower or northern part of the drainage area, where the topographical relief is small and chiefly drumloidal. The middle and upper sections of the basin lie near the extreme limit of the ice invasion. The ice erosion was here consequently of less duration and less effective than farther northward, and the grosser topographic features were not materially changed. The saliencies were somewhat pared down, or the surface partially smoothed, with considerable filling of drift in the valleys. The heavier dams of drift, interfering with the resumption of the stream drainage, were usually formed in the lateral valleys at their junction with the main or river valley. As a consequence of this closing of the mouths of the side valleys, lateral local lakes were produced, and the outlet or waste-weir was frequently over the rock-wall of the old valley slope, the morainic filling being usually higher in the middle of the valley. The final result has been the making of postglacial rock-ravines near the embouchure of several streams tributary to the river in the same manner as the formation of the head of the Portage canyon.

One of the largest of these rock-cuts in lateral valleys is near the mouth of Caneadea creek, upon the west side of the river. An immense moraine and kame deposit blocks the side valley, and the consequent local morainal lake was drained by the outlet cutting down through rock upon the south side of the dam.

A very typical and interesting example of postglacial rock-cutting is seen at Angelica. The short rock-ravine, over 100 feet deep, in the course of Angelica creek has been formed upon the northwest side of the ancient valley. This moraine dam, which was a distinct ridge across the valley, consisted of unenduring material, and has been so far removed, apparently by atmospheric agencies, that now it is not nearly so high as the top of the rock-cut.

Other postglacial rock-cuts in the course of direct tributaries of the river occur in the channels of Silver lake outlet, Wolf creek, Canaseraga creek, Wiscoy creek, Cold creek, Black creek, White creek, Van Campens creek, Phillips creek, Vandemark creek, Knight creek, Chenunda creek, and probably many others; also in the west and middle branches of the river.

In the indirect or secondary tributaries of the river rock-cuts are doubtless numerous, not counting those of stream channels which are wholly postglacial. One of the largest is the channel of Kishawa creek, some six miles south of Mount Morris, between the stations Sonyea and Tuscarora on the Western New York and Pennsylvania railroad. A small but interesting example may be seen near Swains station on the Erie railroad in the channel of a small stream entering the upper Canaseraga at that place; also in the Canaseraga near Dansville. In the majority of cases observed these rock-cuttings occur upon the north or west sides of the preglacial valleys.

The local morainal lakes will be described later in this paper.

BURIED CHANNELS OF THE GENESEE.

The two old channels of greatest interest and of uncertain location are those of the ancient river, one below Portageville and one past Rochester. In any attempt to locate the ancient waterways it must be recognized that they were broad, open valleys, comparable to the known adjacent sections of the valley. The buried Genesee valley below Portageville must be one to two miles wide. The writer is confident that the preglacial course of the river lay through what is now Kishawa Creek valley, in which lies Nunda village. This was suggested by Dr James Hall* as long ago as 1840, and will probably stand as against all other suggestions. The facts sustaining this opinion are out of place in this paper.

Less confidence is felt concerning the former course past Rochester. It seems most probable that below Avon the old valley turned eastward and connected with the depression of Irondequoit bay.

SEQUENCE OF EVENTS IN THE GEOLOGICAL HISTORY OF THE GENESEE VALLEY.

INTRODUCTORY STATEMENT.

For the full appreciation of the lacustrine phenomena in the Genesee valley it is desirable to have in mind the sequence of events in its geological history. Theoretically the following steps in the history may be predicated:

ERA OF PREGLACIAL SUBAERIAL EROSION.

This was by far the longest stage in the whole history. From the time when the region was first lifted out of its marine condition of submergence and sedimentation, probably during the later Devonian or the Subcarboniferous, down through the millions of years to the Glacial period, this stage endured continuously. During this time the superficial rocks

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*Fourth Annual Report on the Survey of the Fourth Geological District: James Hall. New York Assembly Documents, No. 50, 1840, pp. 431.

were decomposed and the region was deeply scored and eroded by atmospheric forces and stream action. The main features of the present topography were impressed upon it during later geologic time, possibly since the Cretaceous.

EPISODE OF LAKES BY ICE-ADVANCE.

With the invasion of the ice-sheet of the Glacial period the northward drainage was blocked and the waters were ponded in the main and tributary valleys and compelled to overflow southward. The levels of these static waters were *successively higher* as the ice closed the outlets from the lower toward the higher elevations of the region. The deposits in the glacial lakes may have been considerable, derived from the ice-drainage as well as from the land. The subsequent abrasion by the heavy ice-sheet would largely remove or modify these early lake deposits, yet traces of them may probably be recognized, although little may ever be known of the character of these lakes.

EPISODE OF GLACIATION.

The ice-invasion resulted in largely removing the disintegrated rocks, and may have cut the solid rock upon the saliencies, especially on the stoss sides of the hills. However, the erosion of rock strata was probably not great in the Genesee valley, the work of the ice being chiefly a smoothing of the eminences and an accentuation of the north and south forms and a filling of sections of the valley with heavy deposits of wreckage derived from regions lying northward.

EPISODE OF LAKES BY ICE-RETREAT.

The northward retreat of the ice-wall resulted in a second series of glacial lakes at successively lower levels, which are the special subject of this paper and will be described below.

EPISODE OF MORAINAL LAKES.

Subsequent to the retreat of the ice and the draining or lowering of the glacial lakes by removal of the ice-dam numerous morainal lakes were left in the main and tributary valleys, held up by the barriers of drift. All these moraine-dammed waters have been drained, many outlets cutting through rock upon the slopes of the ancient valleys (see page 427). The lacustrine phenomena of these morainic lakes are left commingled with the phenomena of the ice-dammed lakes and the subsequent streams.

ERA OF POSTGLACIAL SUBAERIAL EROSION.

In every section of all the valleys the latest aqueous action is the work of streams. The river and all its tributaries found their valleys more or less filled with drift of several kinds—moraine drift, kame drift and lake sediments—and at once proceeded to open their channels. The reëxcavation of the valleys has been wholly, and the leveling of the drift partly, the work of the present streams. A renewal of the conditions of atmospheric destruction in all its phases over all the area marks the last and present stage.

It will be noted as an important fact that there is a commingling, especially in the lower parts of the valleys, of the deposits formed during the last three stages of the history. The terraces of the glacial and of the morainal lakes and the detrital plains of the streams are intermingled and confused. Sometimes it may not be possible to distinguish them.

Phenomena of the glacial Lakes.

EVIDENCES OF WATER-PLANES.

The phenomena proving the former existence of static water at high levels in the Genesee valley are superabundant. To the observant eye terraces and plateaus are scarcely ever entirely out of view. The phenomena are of the various kinds characteristic of water margins, with the addition of those peculiar to ice-dammed waters. They may be divided into three classes:

(*a*). Those marking the true level of the water, as beaches, lake-cliffs and strictly shoreline features. For several reasons these features will be weak. The waters were not very long stationary at any particular plane, as they varied with the season and the down-cutting of the outlets, and the expanse of water was not sufficient to permit of strong wave action. The beach phenomena would give the most accurate data for altitudes of the water surface, but they have not been observed.

(*b*). Plateaus of superior level. Such are the deltas, of two kinds: (1) Land-stream deltas, which will be recognized by their resting against the valley walls and their relation to existing streams, which will have bisected them; (2) Glacial-stream deltas occur in the valley, removed from the shore or isolated. By the removal of the ice-wall against which they were headed the glacial streams which produced them were withdrawn and such deltas are not bisected. They will usually be confused with kame drift, to which, indeed, they are related. Even standing alone, as butte-like plateaus, they resemble in their general form truncated or leveled kames, which are of inferior levels. The allowance to be made for the height of a true delta above the lake surface is a variable element.

(*c*). Plateaus and terraces of inferior level. Here are included the greater proportion of phenomena, as shoreline benchings, terraces of construction (wave-built), terraces of erosion (wave-cut) and truncated hills of moraine or kame drift. The allowance to be made for the higher altitude of the water surface is here assumed in general at from 10 to 20 feet, or less for coarse materials.

In the very rapid and cursory examination of this large region it has been impossible to discriminate as to the exact nature of the plateaus and terraces measured for determination of water-levels. The one essential fact was the certainty of their being phenomena of water-planes. For the purpose of correlation with the several lake outlets only the highest terraces of each section are relied upon, which are far above any possible stream action or even the level of morainal lakes, and too far reaching to be the result of mere lakelets upon the side of a glacier lobe.

As each stage of these glacial waters covered only a limited section north and north, and had its own independent levels and, geologically speaking, was of brief duration, the distortion of water-planes due to differential northward uplift is probably of small amount.

DRAINAGE OUTLETS.

Upon the map (plate 19) the important channels across the divides are indicated by lines and the altitude above tide by figures, placed transverse to the line of water-parting. Those at the three cols in which the river heads were doubtless contemporary outlets of the primary lakes. One of these, between Rose lake and Oswayo, is believed to have subsequently taken the water from the other two. The channel northwest of Genesee village is cut down to the grade of the valley. This, like the preceding Oswayo outlet and the subsequent Cuba outlet, carried the Genesee waters to the Allegany river and the Mississippi. The third great outlet with two subordinate phases was upon the eastern divide above Hornellsville, leading to the Susquehanna waters. The next outlet was over the western divide into the great lake Warren. These outlets will be briefly described below in connection with their respective lakes.

THEORETICAL STATEMENT.

A general theoretical statement of the succession of glacial lakes will clear the way for the detailed description of those lakes. We have a comparatively narrow valley, with numerous side tributaries, sloping northward or toward the retreating ice-front. By the northward shifting of the ice-dam, the impounded waters fell from time to time to the level of each successively lower outlet over the divide. In any section of the valley the highest water-plane should correspond to the lowest outlet uncovered. In want of knowledge it is assumed that the ice-front was in general an east-and-west line. As a matter of fact, the highest water-planes do so correlate with the theoretical outlets.

DESCRIPTION OF THE GLACIAL LAKES.

FIRST STAGE: THREE PRIMARY LAKES.

Outlets.—Their outlets were by the headwaters cols.

A glance at the map will show that the Genesee river originates in Potter county, Pennsylvania, in three subequal, northward-flowing streams, known as the east, middle and west branches, which unite near the village of Genesee (formerly called Genesee Forks). These streams lie in comparatively deep valleys, carved out of the high tableland, the intervening ridges being higher than the headwater cols. The writer has not visited the sources of these three streams, and his information concerning the divides is obtained from other persons, and particularly from Professor N. S. Shaler, who has kindly loaned some unpublished notes of a visit made a few years since to those headwaters.

The streams are described as heading in swamp cols, but with no conspicuous or strong channels or scourways leading southward from the divides.

Life history.—As the high land about the sources of these streams was uncovered by the ice the glacial waters were at first ponded in many lakelets and escaped by numerous outlets. Later, by a further retreat of the ice, these lakelets were drained or blended, until, theoretically, there was an episode during which a lake existed in the valley of each of the three branches of the Genesee. These were not very important in any respect, but, to make a complete history, must be considered. The lake phenomena and outlet channels should, theoretically, not be well developed for the following reasons:

(1) The life of these separate lakes was very short, as a few miles further retreat of the ice-front inaugurated the next stage of the glacial waters. (2) The surface of the lakes was probably very fluctuating. (3) Each valley caught the drainage of only a very limited portion of the ice-front. If the ice-front was generally east and west, then the drainage both east and west of the narrow Genesee basin drained directly in south-flowing streams (see map); but if the basin was occupied by an ice-lobe, the waters from the sides of the lobe further north found lower outlets. (4) The ice-front was perhaps comparatively thin and supplied for the area a small amount of water. The district is close to the limit of the glaciated area; indeed, the west and middle branches of the Genesee have their sources in the great terminal moraine.*

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* Second Geol. Survey of Penna. Report Z, Terminal Moraine, pp. 141–143 and moraine plate vi.

The waters of the east-branch lake, by the Ulysses-Brookland col, flowed to the Susquehanna river; those of the other two lakes reached the Allegany river.

Wlth the further recession of the ice-front it is possible that for a brief period the eastern lake found a lower outlet and that the two eastern lakes blended into one. It is doubtful if the outlet by Bingham, toward Harrison valley, the lowest of the east-side cols, was opened before the junction of the valley was uncovered, thus allowing all the waters to flow west by the Oswayo outlet. In any case, this phase was so brief that, with the present uncertainty, no further note of it is taken.

SECOND STAGE: PENNSYLVANIA LAKE.

Outlet.—The outlet was by Rose lake col to Oswayo creek and Allegany river.

As soon as the ice had uncovered the high land between the creeks south of Genesee village, the three primary lakes blended into a single sheet of water having the level of the lowest outlet. This was undoubtedly the outlet of the west-branch lake, by Rose lake to the Oswayo creek, which is about 200 feet lower than the more southern outlets and at least 100 feet lower than the Bingham outlet. From the scanty information attainable, this is believed to be the most capacious of the headwater outlets.

Life history.—This lake could not have existed long, as the northward shifting of the ice-front only a few miles opened a much lower pass and inaugurated a more important stage of the glacial waters.

THIRD STAGE: WELLSVILLE LAKE.

Outlet.—The outlet was by " Stone Dam " col to Honeoye creek, Oswayo creek and Allegany river.

From the parallel of the Genesee forks north to the parallel of the Stone Dam col is about three miles. With the opening of the latter channel the waters fell 400 feet, and this level, with some down-cutting of the outlet, endured for a long period.

This ancient outlet channel is at the head of a short branch of Marsh creek, about four miles from Mapes station, on the Buffalo and Susquehanna railroad. The locality is named after an abandoned milldam of stone in the vicinity. The channel is a remarkable rock-gorge, cut down in purplish shales to almost the grade of the Genesee valley. Riding from Mapes station to the water-parting the rise is almost imperceptible, but Mr Pierce says there is a difference in altitude of 45 feet. The divide is a swamp, filling the bottom of the narrow valley and extending over one mile. Eastward to the Genesee and westward by the Honeoye creek to the Oswayo creek at Shinglehouse the waters are sluggish. The swamp and the slopes of the gorge are occupied with primeval forest, and the dimensions could only be estimated roughly. The width of the rock-gorge at bottom was judged to be about 1,000 feet. The weathering of the steep walls of soft shales has produced talus slopes and detrital cones which bury the edges of the old channel and over which the wagon-road climbs in order to avoid the swamp. The middle of the channel is buried under vegetal accumulation, the swamp being, it was estimated, 40 to 60 rods wide. The rock-walls, which are steeper than any preglacial valley slopes, are perhaps over 1,000 feet high. Apparently this was a preglacial col which has been deepened and widened by the glacial waters. The amount of down-cutting by the glacial stream is suggested by the height of a delta at the mouth of the Stone Dam gully near the east end of the gorge, which was estimated to be 70 or 80 feet higher than the divide, indicating a lowering of the channel of not less than 60 or 70 feet. Very likely it was greater. The present altitude of the col is given by Mr Pierce as 1,600 feet.

Water-levels.—In the upper part of the Genesee valley, from the forks of the river to below Wellsville, are numerous conspicuous phenomena of static water which correlate with the Stone Dam outlet. Many of these terraces were observed, and some of them measured, before the outlet was discovered. At that time they were puzzling, as it was not known that there was any pass through the divide so near down to the grade of the valley.

It is probable that delta deposits and wave-cut terraces will be found in the valleys of the headwaters at an altitude near 1,700 feet or higher, but an examination has not been made. At Genesee village there are several good plateaus of water-worn material. Taking the station of the Buffalo and Susquehanna railroad as datum at 1,624, the cemetery terrace, south of the village, is 1,734 (aneroid). Nearly corresponding terraces are seen upon the west and northwest and shoreline benchings upon the east. Northeast of the village, one-half mile up Cryder creek, are gravel plateaus at 1,690 (aneroid). Levels of the same erosion plane are seen at Shongo station, north of Genesee. Near Graves crossing is a flat-topped, butte-like plateau, 1,670 (aneroid), with a similar level at the mouth of a west-side creek. Fine terraces are seen in the northward distance at corresponding height. A terrace near the east end of the channel was estimated at 1,680. At Stannards Corners, toward Wellsville, are conspicuous plateaus and terraces, unmeasured, but certainly of a plane similar to those mentioned above. Within two or three miles of Wellsville are pronounced levels, estimated at somewhere between 1,620 and 1,650.

Five miles east of Wellsville, on Dykes creek, a small delta at the mouth of an east-side creek was determined by close estimate at 1,610.

The upper terraces seen further down the river at Scio, Belmont and Belvidere are evidently of the Stone Dam plane, but they have not been measured. The valley here is lower in altitude and the strongest levels were produced by the waters of the next stage. In the valley of Van Campens creek, around Friendship village, there are conspicuous plateaus, roughly estimated at about 1,625 to 1,645 feet. These, however, are not the summit levels, as this valley was the basin of an independent local glacial lake (see page 447), and are consequently not conclusive.

It should be noted that in general the terraces become lower as we go northward. Theoretically, this is to be expected, as northwardly the terraces are successively later in time and the outlet was constantly lowering.

This lake, named the "Wellsville" lake, after the chief village within its limits, existed for a long period and its work of shore erosion and planation is very evident. It came to an end through the capture of its waters by a lower outlet than the Stone Dam channel. The lower outlet was opened when the ice-dam uncovered the point of high ground in the town of Belfast on the western side of the valley, between the river and Black creek.

FOURTH STAGE: BELFAST-FILLMORE LAKE.

Outlet.—The old outlet by Cuba is another fine example of an abandoned river channel, but of a very different type from the Stone Dam channel. The latter was a narrow rock-gorge. The Cuba channel is in a broad, open, north-and-south valley. The divide north of Cuba is a smooth plain, about one-half mile wide and continuous with the valley bottom northward. Its present altitude is 1,496 feet. The old Genesee valley canal traversed this pass, as does the successor of the canal, the Western New York and Pennsylvania railroad. For a stretch of several miles, from Black Creek station to below Cuba, the railroad retains the 1,496-foot level. The Erie railroad enters this channel from the eastward at Cuba village upon a terrace, which is apparently an old flood-plain, 40 feet above the present channel. Further south the walls of the valley seem to be rock, about one-third mile apart. All the way to Olean the valley retains a fairly uniform width of about one-third to one-half mile. Fragments of high, bordering plains and deltas at mouths of side streams are seen at a height of 20 to 30 feet above the present floor of the valley. The fall from Cuba to Olean is only 64 feet in 14 miles. Northward from Black Creek station to Rockville the fall is 75 feet in four miles, and to Belfast, three miles farther, 109 feet additional.

The col may have been partially filled with drift. The amount of down-cutting or removal of the damming drift is difficult to estimate. The waters seem to have leveled the drift without cutting to rock, the channel being spacious and near to grade.

Water-levels.—This stage of the Genesee waters covered a longer stretch of the valley than any other and probably endured for a longer time than any other of the lakes previous to the Warren stage. From Belfast to Portageville the summit planes belong to this stage. The waters, however, buried the upper valley some distance above (south of) Wellsville, but from the southern limit of the waters to a point above Belfast these planes are overtopped by those of the previous Wellsville lake. They are, however, generally so much stronger than the earlier Wellsville terraces that they can probably be recognized. In this basin we have for data the reliable altitudes of the Western New York and Pennsylvania railroad, based upon the canal levels. This is the main section of the old river valley. It is in places two or three miles wide, but the ancient borders are often obscured by the heavy deposits of drift, which also frequently form massive hills in the midst of the valley, morainic, kame-like and esker-like. These drift hills have not usually retained strong terracing by the static waters, perhaps on account of their unenduring character and the great destruction they have been subjected to in the middle of the valley. The higher leveling and shore benching cannot be seen well from the middle of the valley or from the railroad, but only from more commanding situations. The lower valley is very rich in stream plains and lower terraces.

Although the high water-planes have been seen at many points in this section of the valley, only a few have been measured or closely estimated, but a number sufficient to serve as examples.

Below Cuba village the bordering plain is 40 feet over the channel, or 1,536 feet. The Erie station is upon this terrace, which is perhaps two miles south of the present water-parting and may indicate some down-cutting and backward erosion by the outlet stream. Terraces corresponding in altitude to this are seen northward by the Cuba reservoir, at Black creek, and indeed almost continually as far north as Rockville. However, these terraces are all in the Black Creek valley, which was the basin of a local lake (see page 448), and it might properly be claimed that they do not prove the level of a larger lake in the river valley. The phenomena are, however, far greater and more imposing than those produced by a local lake. Corresponding summit terraces are found all the way to Portageville, and leave no room for doubt of the larger lake and outlet.

At Belfast and Oramel the terraces are conspicuous, but the altitudes have not been even estimated. Upon the east side of the valley north of Belmont two lines of water erosion show clearly, seen from the wagon-road near Belvidere. The higher was estimated as in the neighborhood of 150 feet above the river plain, or about 1,520 feet; it is probably higher rather than lower, as such estimates of distant points usually fall under the truth.

At Caneadea there are several distinct high levels of erosion, the lower ones belonging to the next stage of the static waters. The highest level upon the west side of the valley is upon a kame or moraine deposit, which dammed the lateral valley and produced the tributary morainal Rushford lake (see page 451), and the level is believed to belong to that local lake. A lower terrace on the river side of the moraine is believed to be a delta of the Rushford lake outlet or a plane of the Genesee waters, at an altitude of 1,514 to 1,530 feet (aneroid, with spirit-level).

At Fillmore the lower of the elevated terraces were measured by spirit-level and a careful estimate of the added height of the distant summit terrace gave a result for the latter of somewhat more than 1,500 feet.

FIFTH STAGE: PORTAGEVILLE-NUNDA LAKE.

Outlets.—The immediate or primary outlet was by the upper Canaseraga channel, the waters falling into Dansville lake. The ultimate outlet was by the Burns channel to the Chemung—Susquehanna.

General description.—In connection with this and the succeeding stage there is a complication of conditions and phenomena making a difficult but fascinating problem. For the understanding of the matter by the reader it is necessary to describe the main topographic features of the district comprised by a circuit of Portageville, Nunda, Canaseraga, Dansville and Mount Morris, and give an outline of the history.

At Portage gorge the river drops into its postglacial channel, reaching to Mount Morris. Upon the west the land is high. Upon the east the ridge dividing the Genesee channel from the broad, low valley of the Kishawa creek (Nunda valley) is lower, ranging from 1,100 down to 800 feet. The present Kishawa valley heads in a heavy moraine south of Nunda village and a branch leads southeast to a col. From this col, a few miles north of Swains station, a fine rock channel leads south and then east to Canaseraga village. In this old, abandoned river channel rises the Canaseraga creek, which, one mile east of Canaseraga village, drops into the gorge locally known as Poags Hole; then a few miles north emerges into the broad Dansville valley and finally joins the Genesee river near Mount Morris. The main divide between these waters and the Susquehanna waters is at the head of Poags Hole, one or two miles north of Burns station on the Erie and the Central New York and Western railroads.

The history in brief seems to be as follows: Before the Cuba outlet

FIGURE 1.—OUTLET CHANNEL OF THE FIFTH-STAGE WATERS.

View looking south over Swains village.

FIGURE 2.—ULTIMATE OUTLET CHANNEL OF THE FIFTH-STAGE AND SIXTH-STAGE WATERS.

View of the Burns-Arkport channel, looking north, up channel, from the west side flood-plain at Arkport village.

OUTLET CHANNELS OF GLACIAL GENESEE LAKES.

ceased to be effective it is probable that Poags Hole and the Dansville valley were the site of a local glacial lake,* the Dansville lake, overflowing past Burns to the Chemung river. When the ice uncovered the region of Portageville the Genesee waters found an avenue of escape, 150 feet lower than Cuba, over the morainic dam east of Portageville and filled the upper Nunda (Kishawa) valley to the height of the col north of Swains. Overflowing by the Swains-Canaseraga channel into the Dansville lake, the water ultimately escaped by the Poags Hole col past the sites of Burns and Hornellsville to the Susquehanna.

Primary outlet.—The present water-parting between the Nunda valley and the Swains-Canaseraga channel is at Ross crossing on the Central New York and Western railroad, four miles north of Swains. This point is the southern limit or head of a heavy moraine which fills the head of the Kishawa valley and descends rapidly to the north toward Nunda.

The rock channel begins immediately south of the divide and extends past Swains, Garwoods and Canaseraga to the head of Poags Hole, two miles north of Burns, a length of 12 miles, being traversed the whole distance by the Erie and the Central New York and Western railroads. At Garwoods and at Canaseraga other valleys join and the channel is there expanded and indefinite, but with these exceptions the channel preserves its fine and uniform characters as an old river-course (see plate 20, figure 1). It has a very steady width of one-fourth to one-third of a mile, with abrupt banks of Portage shales and curvatures of large radius. The bottom of the channel is now flat and swampy, the stream being insignificant. The mouths of side ravines are left higher than the channel bottom, and bisected deltas, 20 to 40 feet high, are frequent. The altitude of the divide is 1,320 feet. The fall from there to Swains, four miles, is 13 feet; from Swains to Garwoods, two miles, is 30 feet; from Garwoods to Canaseraga, two miles, is 20 feet; or 60 feet fall for the first eight miles below the divide. This channel terminates one mile east of Canaseraga.

Ultimate outlet.—The waters of the fifth stage were poured into the Dansville local lake one mile east of Canaseraga village. The second, or ultimate outlet to the Susquehanna waters, will be described in connection with the sixth stage of the Genesee waters.

Water-levels.—The erosion plane of this lake extends as far up the valley as Belfast, but it is the highest or summit level only north of a parallel cutting the valley just south of Portageville. Being lower and nearer the center of the valley, these are the most conspicuous levels visible from the railroad throughout the extent from Portageville to Belfast. They have been measured at numerous points, as follows: Two miles

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* Described in a former paper, Bull. Geol. Soc. Am., vol. 6, pp. 358, and now believed to have been later joined with the Genesee waters of the sixth stage.

southeast of Belfast, 1,375 (aneroid); east of Oramel, 1,325 (aneroid); Caneadea, 1,343 (aneroid), 1,356 to 1,370 (spirit-level); Fillmore, 1,344 to 1,370 (spirit-level); Portage, many points accurately measured, ranging from 1,322 to 1,360. At Portageville we know the exact height of the plateaus. The Erie railroad passes over the scoured gravel plains at Dalton station, 1,330, and at Hunts station, 1,333, and at Portage station has cut into a broad, flat, gravel plateau 10 to 12 feet. The verified altitude of the Erie trestle over the Genesee is 1,314 feet. The station is one foot lower and the fine erosion plane at the station is 1,323 to 1,325 feet. By hand level and aneroid the numerous terraces around and east of Portageville are made, as given above, 1,322 to 1,360 feet. West of the village one shoreline bench, which probably marks the highest water surface, is judged to be about 1,370 feet. The gravel plateaus east of Portageville are the leveled moraine or kame drift which blocked the old valley and diverted the river. With the first uncovering by the ice the ponded waters swept over this drift to reach the Nunda valley and the Swains channel. A well defined scourway is seen on the highway toward Hunts, with altitude 1,340 to 1,350 (aneroid). Later the waters escaped over the lower ground north of Portageville, but they did not fall much below this level during the fifth stage, as the bottom of the present Swains divide is 1,320 feet.

At Angelica a delta was measured by aneroid from uncertain datum as 1,435 feet, and east of Belfast are terraces, by aneroid, 1,430 to 1,450 feet. These do not correlate with the summit levels of either the fourth or fifth stages, but can be properly regarded as marking a pause in the subsiding waters. These are the only measurements made in the whole valley which do not accord with an outlet plane.

SIXTH STAGE: DANSVILLE LAKE.

Outlet.—The outlet was by middle Canaseraga gorge (Poags Hole), past Burns and Hornellsville, to Canisteo creek, Chemung and Susquehanna rivers (see plate 20, figure 2).

The Burns-Arkport channel is the grandest of the abandoned water-courses. Its effective life was probably shorter than some others described above, but it carried a much greater volume of glacial water. The channel is about three-fourths of a mile wide, usually with drift banks, and extends from the edge of the Poags Hole gorge, one and one-half miles east of Canaseraga, past Burns and Arkport to Hornellsville, a distance of twelve miles. Its fall in that distance is about 50 feet, but four-fifths of this fall is in the last six miles. Between Burns and Arkport, three miles, there is a fall of only three to five feet. Below Burns the valley bottom is comparatively smooth, but above Burns, toward and at the divide, the channel is somewhat swampy and uneven, and the vegetable growth has not covered the old river gravels. The divide is under poor cultivation, the soil being coarse sand and gravel with low mounds and longitudinal bars of washed gravel. The material is so porous that no recognizable stream is seen above Burns. The altitude is about 1,210 feet. The plain of the divide ends suddenly to the north in the deep Poags Hole gorge, which has been cut out of the drift-filling which apparently occupies a great depth of the ancient valley. Upon the west side of the channel, along by Burns, there still remains about one-half mile in width of the moraine and kame filling. At Arkport there is a group of drift hills on the east side of the channel. Detrital or flood plains are seen all the way from Burns to Hornellsville, at a height of 15 to 30 feet over the channel.

Water-levels.—This stage of the glacial waters began when the receding ice-sheet uncovered the ridge between the Nunda and the Dansville valleys down to an altitude lower than the Swains divide. Gradually the Swains channel was abandoned as the waters fell to the level of the Dansville lake, and the Burns col became the direct and only outlet.

With this fall of the Genesee waters the local Portageville morainal lake was established. The moraine dam was left at a height of 1,323 to 1,340 feet, east of Portageville, but we have no means of knowing the amount of drift-filling which has been cut away by the river over the head of the Portage gorge. The fall of water surface from the fifth to the sixth stage was about 100 feet, as the Burns outlet had been partially cleared by the local lake drainage.

Perhaps the local Portageville lake cut down the drift top of its dam so rapidly as to retain a level not far above the subsiding glacial waters, but when the rock was reached the morainal lake was certainly left behind. The top of the rock at the head of the Portage gorge, beneath the Erie trestle, is 1,240 or 1,250 feet. The numerous and conspicuous lower plateaus in the Genesee valley, from Portageville up as far as Caneadea, ranging from 1,160 to 1,270 feet, undoubtedly belong to the local morainal lake and not to the glacial waters.

The undoubted terraces of the sixth stage must be found north of or below the Portageville moraine. Such are to be seen in the present valley of the Genesee (the Saint Helena valley), in the Kishawa valley and in the Dansville valley. The only strong plateaus that have been closely estimated in the Genesee valley are the delta terraces at the mouth of Wolf creek, on the west side, a few miles north of the Portage ravine. The summit was estimated from aneroid measurements at 1,275 feet. Some three miles north of Wolf creek a broad clay terrace or silted plain was measured by aneroid at 1,225 feet.

In the Kishawa valley no measurements of this plane have been taken. The prominent high plateaus about the head of the Dansville valley* belong to the antecedent phase of the local lake and mark the earliest high levels (see plate 21, figure 1), but the lower extensive plateaus about Poags hole mark the latest levels of the water; these are as low as 1,220 feet, or only 10 feet over the present channel. A correction of the datum in the Dansville valley makes the summit plateau on the east side of Poags Hole, or west of the Central New York and Western railroad station, 1,262 feet, and the highest terraces near Conesus fall into levels under 1,200 feet, the latter consequently belonging to the waters of the next stage.†

SEVENTH STAGE: WARREN TRIBUTARY LAKE.

Outlet.—The outlet was across the western divide into lake Warren.

This stage of the glacial Genesee waters is at the time of this writing not entirely certain in all features, partly on account of the indefinite character of the phenomena and partly for lack of detailed study of the area involved.

The western divide between the Genesee and the Tonawanda drainage is a broad, irregular land mass which declines northward from altitude of about 1,400 feet near Warsaw to about 900 feet near Batavia. As the ice-sheet was removed from this northward-sloping divide at an altitude of about 1,200 feet, the glacial waters began to spill over westward into other waters tributary to lake Warren. The sixth stage in this history did not come to an abrupt end by the sudden opening of a single outlet far below the height of the Burns-Arkport outlet, but terminated gradually by the uncovering of the irregular dividing ridge above described. The earliest overflow seems to have occurred at a point about two miles south of the village of Bethany, where a narrow scourway of small capacity is seen crossing the divide at an altitude by aneriod of about 1,200 feet. Somewhat larger scourways at slightly lower altitude are found one-half mile south of the village, and still larger ones one-half mile north of the village at altitude of about 1,100 feet. The largest water-course observed is some two miles north of Bethany and directly west of East Bethany, where a well defined channel over one-fourth mile wide is cut down to rock. This shallow pass is traversed by the Delaware, Lackawanna and Western railroad, which to secure easier grade has cut 10 feet into the decomposing shales. The present water-parting is about two miles west of East Bethany station, where the rock-sill of the waste-weir has an altitude of about 1,030 feet, or 180 feet lower than the outlet of the sixth stage waters. From this scourway no single large channel is

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* Vol. 6 of this Bulletin, pp. 358-360.

† This is a correction of the altitude given in the former paper, vol. 6 of this Bulletin, p. 361.

FIGURE 1.—WATER-PLANE OF THE DANSVILLE LAKE: FIFTH-STAGE WATERS.

Leveled kame and delta of Stony brook, looking north; Poags Hole gorge at left.

FIGURE 2.—CONTORTED LACUSTRINE CLAYS OF THE NINTH STAGE—IROQUOIS WATERS.

Section of Iroquois clays near present mouth of Genesee river, east side.

WATER-PLANE AND CONTORTED CLAYS OF GLACIAL GENESEE LAKES.

found leading down the slope into the Tonawanda valley, but narrow, steep channels occur in the shales. The latter decompose rapidly under atmospheric agencies, and the ancient channel has probably been cut and obscured by later erosion.

In the region of East Bethany the ground consists of broad stretches of level silts or sand plains, apparently spread out by lacustrine waters.

North of the East Bethany channel is a low east and west ridge of irregular and morainic character, which apparently marks the location of the ice-front during the time the East Bethany channel was effective· Between that ridge and Batavia, four miles northwestward, the drift surface is shaped into east and west forms, at least partially due to the erosion by water currents subsequent to the ice occupation. The altitudes of the scourways are from 950 feet down to 900 feet near Batavia.

The broad plain of sand and gravel on which Batavia lies, with an altitude of 890 feet, is probably the effect of the leveling of the kame and moraine drift by these lake waters during the close of the seventh stage. The ice-front was then north of Batavia and the seventh-stage waters had blended with the local Attica lake which occupied the Tonawanda valley. This episode was probably contemporary with the last phase of the ice-dam holding the Warren waters in check west of Batavia.*

The altitude of the blended Genesee and Tonawanda waters, which was not far above 900 feet, was determined by the height of some hypothetical channels over the western border of the Tonawanda valley into the Warren waters, which latter waters lay only a few miles to the west at an altitude of 860 feet.

Water-levels.—The water-levels of this stage have not been closely studied. Various planes with altitudes from 1,200 down to 900 feet may probably be correlated with this episode.

The western and southern limits of the lake were not very different from those of the preceding stage. The eastern and northern limits are unknown, being dependent upon the position of the edge of the ice-sheet.

EIGHTH STAGE: WARREN WATERS.

Outlet by Chicago to the Mississippi.

During the time covered by the lacustrine history of the Genesee valley as described above other glacial lakes were formed on the north slope of the continental divide both east and west of the Genesee valley. The greatest of all the glacial lakes in the Laurentian basin was lake Warren, which had its outlet past the site of Chicago to the Mississippi drainage,

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*See article by Mr Frank Leverett on "Correlation of New York Moraines with Raised Beaches of Lake Erie," Amer. Jour. Sci., vol. l, July, 1895, pp. 1–20.

as the eastern or Ontario end of the Laurentian depression was filled with ice. At the time which we have now reached in this history of the Genesee valley the Warren waters had forced their way eastward as far as western New York. The heavy beaches have been traced along the south side of lake Erie northeastward to Alden and Crittenden, west of Batavia, where they have an altitude of 860 to 865 feet.*

During the seventh stage the Genesee waters had been draining over the western border of the valley into the Warren waters and gradually approaching the level of the latter. Finally, when the western border of the Genesee valley was uncovered down to about 860 to 870 feet, the Genesee waters blended with lake Warren. This required the desertion by the ice of the point of high land reaching north to Batavia. A terminal moraine east and west of Batavia indicates a considerable lingering of the ice-front at this line, but with the retreat of the ice the Warren waters invaded the Genesee valley and spread far eastward.

The lower Genesee valley was flooded up to an altitude as high or higher than the beaches west of Batavia (865 feet). The waters extended up the valley as far as Mount Morris, where the river at its debouchment built a delta in the lake. The Dansville valley was also flooded, and indeed the Warren erosion and delta planes are to be found throughout the region between 850 and 900 feet altitude.

There remains much uncertainty as to the eastward extent and altitude of lake Warren. Many phenomena have been noted and strong erosion planes found as far east as Ontario county, but a systematic study of the Warren phenomena has not been made in this region, and further discussion will be reserved for a future paper.

When the Genesee waters fell to the Warren level a morainal lake was left in the new portion of the river valley above Mount Morris, and the rock-cut at the "high banks" was begun (see page 450).

During the stage of Warren waters the low plain of the Salina and Niagara terranes, lying north of the Devonian plateau and under 850 feet altitude, received a heavy burden of detritus derived from the reëxcavation of the higher river valley. Such depressions in that plain as were not filled by ice-drift were silted up during this lacustrine stage, and the leveling was subsequently completed by the waves and currents of the receding margin of the falling lake. Along the present river-coarse each point was also at one time the locus of the river-delta deposits. In consequence of this filling and leveling of the Warren lake floor in the

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* For description and discussion of these phenomena the reader is referred to the writings of Warren Upham, J. W. Spencer, G. K. Gilbert, Frank Leverett and F. B. Taylor in various geological journals. A condensed review of the extinct lakes of the Saint Lawrence basin, with bibliography, will be found in the American Journal of Science, vol. xlix, January, 1895, pp. 1–18.

Genesee region the area is today comparatively smooth, except for recent stream excavation and the drumloid ridges.

A brief pause of the glacier front at the southern edge of Rochester had accumulated an east-and-west crescentic kame-moraine,* which after the withdrawal of the Warren waters probably acted as a low barrier in the course of the river and caused a shallow morainal lake (see page 450). As the waters fell the river extended its channel over the abandoned lake beds. From Mount Morris to below Avon it meandered over the silted floor of its old valley. Beyond Avon the ancient valley is lost, and the river wandered northward among the drumloid ridges for 10 miles and then took a more direct course, east of north. In the cut through the moraine the river is now on rock, and this point, locally known as the "rapids," is the extreme head of the Rochester canyon of the Genesee; but the excavation of the gorge did not begin in earnest until the next, or Iroquois stage.

The Warren stage ended only when the ice-dam by its melting opened up an outlet channel in the Mohawk valley lower than the Chicago channel. The waters then fell, how gradually we do not yet know, to the level of the "Ridge road," at Rochester, and the next and last stage of the glacial waters was inaugurated.

NINTH STAGE: IROQUOIS WATERS.

Outlet by Rome to the Mohawk and the Hudson.

To glacial geologists the characters in general of lake Iroquois are too well known to need description here. A strong beach, locally known as the "Ridge road," extends east and west across western New York with an altitude across Monroe county of 430 to 440 feet. During this episode the Genesee river debouched into lake Iroquois at what is now the northern edge of the city of Rochester and spread out a broad subaqueous delta of silt. This delta is seen more clearly upon the eastern side of the river, extending northward to lake Ontario and eastward to Irondequiot bay, being deeply scored by recent drainage. Numerous boulders and other evidence of ice-rafting occur, and cuttings in the clay reveal contortions due to crushing or pushing of the beds, evidently produced by readvance of the ice or by the dragging of icebergs (see plate 21, figure 2).

The Genesee canyon at Rochester was begun during the Iroquois stage. South of the Pinnacle moraine the Genesee waters were ponded for a time in a shallow morainal lake. North of the morainic dam, at the "rapids," the river was a swift stream with rock channel and broke over the edge of the Niagara limestone at some undetermined point north of the present

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*The Kame-Moraine at Rochester, N. Y. H. L. Fairchild. American Geologist, vol. xvi, pp. 39-51, 1895.

upper falls. At that point the limestone escarpment probably produced at first only rapids in the stream which then for toward two miles flowed in a deepening gorge of Niagara shale until it reached the level of the Iroquois waters. The excavation of the lower part of the canyon did not begin until the Iroquois lake was drained to the Ontario level.

The studies of Mr Gilbert have shown that there were considerable changes in the level of lake Iroquois produced by the differential elevation or warping of the land of the Ontario basin, and it is regarded as probable that the whole region during the Warren and Iroquois episodes was at a much lower altitude as regards sealevel than it is now. The unequal elevation has caused the old Warren and Iroquois beaches to be thrown out of their horizontality and to have now a progressive elevation northeastward.

With the removal of the glacial ice-dam from the valley of the Saint Lawrence, lake Iroquois was drained by the lower outlet and the last of the series of glacial Genesee lakes came to a reluctant end.

TENTH STAGE: LAKE ONTARIO (NON GLACIAL.)

Outlet by the Saint Lawrence river.

It will be understood that this is not a stage of *glacial* waters, but it is included here as completing the postglacial lacustrine history of the Genesee valley.

SUMMARY.

The first stage in the glacial drainage of the valley was from the headwaters to both the Susquehanna and the Ohio-Mississippi, with altitudes of water surfaces over 2,200 feet.

The second, third and fourth stages drained to the Ohio-Mississippi, with altitudes respectively 2,068, 1,600 and 1,496 feet.

The fifth and sixth stages drained to the Susquehanna, with altitudes of 1,320 and 1,210 feet.

The seventh and eighth stages drained to the Illinois-Mississippi, with altitudes from 1,200 down to 880 ± feet.

The ninth stage drained to the Hudson, with an altitude of 435 to 440 feet.

The tenth stage is the non-glacial Saint Lawrence drainage, with present altitude of 247 feet.

Contemporary local glacial Lakes.

IN GENESEE HYDROGRAPHIC AREA.

Conditions affecting formation of local lakes.—Local or restricted glacial lakes could only form in such creek valleys as incline northward or have at least such relation to the river valley that the lobing of the ice-front in the latter would dam the mouth of the side valley while the head of the valley was open.

The directions of lateral stream drainage, as shown by the map, would seem to make such a damming a certainty for all the principal west side streams from the head waters down to Caneadea creek, and also for Oatka creek. For the east side it was certainly true of the Canaseraga, and also of the valleys of the western "finger" lakes, Conesus, Hemlock, Canadice and Honeoye. A multitude of lakelets must have had a brief existence in the great number of elevated and isolated valleys in which lie the sources of drainage, but it is impossible to consider these. A few of the more important lakes of this class will be briefly described as examples.

Knight Creek lake.—The upper part of the valley of Knight creek held a glacial lake, the overflow of which occupied the gorge east of Bolivar. In looking for possible outlets of the Genesee lakes this pass was examined and was found to have been the channel of an extinct stream of considerable size, but not sufficiently large to carry the drainage of the Genesee glacier. The subsequent discovery of the low Stone Dam outlet of the Genesee waters at once explained the Bolivar channel as being the outlet of only the local Knight Creek lake.

This channel is a winding mountain gorge, two or three miles in length, holding now only a small stream. The high walls are rock, the bottom flat and perhaps 600 feet wide, of gentle, steady grade to the col, which is about five miles from Bolivar. The divide is swampy on the Genesee side, and is reported to be drift.

A thousand oil derricks rising through the timber recall the days of the Allegheny county oil boom, when a narrow-gauge railroad used this pass to reach Wellsville. An old profile of this abandoned road makes the altitude of the divide 1,997 (?) feet. No observations have been made upon the phenomena in the local lake basin.

Friendship (Van Campens Creek) lake.—North of Bolivar and Richburg are two cols known locally as "East notch" and "West notch." Each of these seems to have been an outlet of small and transient lakes in the two forks of the south branch of Van Campens creek. The east notch shows little evidence of stream action and is definitely higher than the west notch. The latter has a sharp ridge at the divide, but a well defined, although small, scourway leading south to Richburg. A narrow-gauge branch of the Lackawanna and Southwestern railroad formerly traversed this pass, but the altitude is not known. The small lake drained by this outlet we will call the Wirt Center lake.

The larger local lake in the main Van Campens creek valley, with which the Wirt Center lake soon united, and which will be called the Friendship lake, had its outlet by the west branch of the creek and the drainage was by Champlain and Oil creeks past Cuba. This is a well defined scourway in drift. The divide is smooth, not swampy and about 600 feet wide. The Erie railroad traverses this pass, which has an altitude of 1,692 feet.

Numerous plateaus and terraces are seen in this valley at different heights. Theoretically there are three sets of water-levels in this valley; the local Friendship lake levels, which should be about 1,700 to 1,710 feet altitude; the third stage levels of the Genesee water (Stone Dam outlet) about 1,610 to 1,630 feet, and the fourth stage levels (Cuba outlet) about 1,510 to 1,530 feet.

Black Creek lake.—This lake was the early local lake in the valley of Black creek, with outlet past Cuba, which later was part of the fourth stage waters.

Rushford lake.—From the little that is known of the upper Caneadea valley by observation and report, it seems likely that a local glacial lake existed in the upper part of the valley. The outlet is probably to be found upon some highway leading southward from Rushford to Cuba. A morainal lake (described on page 451) subsequently existed here.

Warsaw lake.—The upper part of the Oatka (Allen) Creek valley must have been filled with glacial waters overflowing for a time probably by Wolf creek into the fifth and sixth stage waters of the Genesee. The phenomena have not been studied. With the retreat of the ice-dam this local lake blended with the seventh stage of the Genesee waters.

Dansville lake.—This lake has been sufficiently described above as corresponding in outlet and level with the sixth stage of the Genesee waters. The details have been given in a former paper,* to which the only amendment now required is that the elevations of terraces should all, with two exceptions, be raised 32 feet on account of correction of datum. The exceptions are the Summit terrace west of Stony Brook station, which is 1,262 feet, and the Culbertson Glen terrace, which remains 853 feet.

Scottsburg lake.—It now seems quite certain that the Conesus Lake valley could never have had an independent level, but must have been, on account of the low pass (907 feet) west of Scottsburg, a part of the sixth and seventh stages of the Genesee waters. Subsequently the valley was held possession of by the Warren waters from the north.

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* Vol. 6, this Bulletin, pp. 358–360.

Springwater lake.—The valley of Hemlock lake was the basin of an independent glacial lake, overflowing at Wayland into Susquehanna drainage. The altitude of its outlet is a little over 1,400 feet, but the main channel across the divide from the Dansville valley into which the Hemlock waters were poured is 1,362 feet. This lake deserves fuller description than can here be given. The same is true of the two other "finger" lakes, Canadice and Honeoye, contained in the Genesee hydrographic area.

TRIBUTARY TO GENESEE AREA.

At least two instances are known where local glacial lakes outside the Genesee basin poured their waters over the divide into the Genesee lakes. These are both upon the east side of the area.

The Rexville lake occupied the valley of Bennets creek and poured over a divide about two miles above Rexville into the head of Cryder creek. This pass is now traversed by the New York and Pennsylvania railroad and has an altitude of 1,912 feet. It is about 700 to 800 feet wide, partially buried under a detrital cone from the south slope, and leads to a well marked channel in a winding rock gorge.

The other instance is a lake in the valley of Canacadea creek, which flows north into the Canisteo. We will name the lake after the creek. The outlet was over a col into the north branch of Dykes creek. The valleys and col are traversed by the main line of the Erie railroad. The divide is a swamp col, 700 to 800 feet wide, with altitude of 1,777 feet. The ancient channel is well defined, 400 to 600 feet wide, and partially in rock-walls.

SUBSEQUENT MORAINAL LAKES.

IN GENESEE RIVER.

Doubtless many pondings of the Genesee river by morainal dams existed after the withdrawal of the glacial lakes. Where the river was able to cut its way through the drift dam without interference of rock, the positive evidence of such lake may be difficult to find. In two cases, however, the river has made deep rock ravines and the evidence of morainal lakes is conclusive. These dams were at Portageville and Mount Morris, and the lakes have already been referred to in the attempt to show the reader the complexity of the static water phenomena.

At Portageville the broad, deep valley was completely dammed with drift, and the river found its outlet over the east rock-wall of the buried valley. After cutting through perhaps 75 feet of drift the river had to cut through about 125 feet of Portage shales before the lake was drained.

This probably required a length of time comparable to the life of one of the stages of glacial waters.

The top of the rock-cut is about 1,250 feet, by estimate, and it seems probable that all the numerous and strong terraces found in the valley from Portage up to Caneadea and below about 1,275 feet altitude belong to the morainal lake. At Portageville there are good terraces at 1,157 and 1,185 feet, and others, by aneroid, at 1,220, 1,255 and 1,265 feet. At Rossburg are conspicuous plateaus, the lower ones possibly detrital river plains, but higher ones at about 1,200 feet and over. At Fillmore the terraces are 1,218, 1,233 and 1,252 feet, and at Houghton is a good terrace, estimated at about 1,250 feet. At Caneadea the terraces are well developed and have altitudes of 1,243 and 1,273 feet.

The Saint Helena morainal lake, which existed in the postglacial part of the Genesee valley above Mount Morris, has not been studied. The top of the rock-gorge, locally known as the "high banks," is not far over 900 feet. The cut, about 300 feet deep, is in dark Hamilton shales and was made during the Warren and Iroquois stages. On account of the narrowness of the valley and the steepness of the slopes, the water planes of the morainal lake are not well preserved, but can undoubtedly be found by searching.

A shallow morainal lake probably existed southwest of Rochester, due to the morainic dam which the river has cut through at the "rapids." This lake could not have been over 560 feet in altitude, the height of the drumloid barrier on the east, and was probably only 540 to 550 feet, the present altitude of the moraine. It could therefore not have been deep, but it extended up the valley several miles, and had a broad expanse east and west, with very irregular form. For the brief episode of its existence this lake received from the river a large amount of detritus, which was deposited as a smooth floor, with an altitude of 525 feet, making the largest level tract in the region of Rochester.

IN TRIBUTARY STREAMS.

Rock ravines with steep sides, occurring in the course of Genesee tributaries, indicate in all cases a diverting of the streams from their old channels. The occurrence of such rock-cuts is given in a preceding section of this paper (pages 427–429). The diversion of the drainage was due to damming by drift, and it follows that such part of the valley above the dam as was not filled with the drift must have been occupied with ponded water up to at least the level of the top of the rock-cut.

The writer has observed but few of the sites of these morainal lakes, and these will be described very briefly.

Probably the largest and deepest of the tributary morainal lakes was the Rushford lake, in the Caneadea valley. The moraine which closed the valley is very massive, being one and one-half miles wide along the river and reaching about four miles west, or up the Caneadea valley to within about one mile of Rushford village. The material is mostly gravel or kame drift, enclosing large kettles and one lake, "Moss pond." The overflow was at the south edge of the moraine, and the creek has excavated a winding channel, with several rock-cuts, along the south side of the old valley. In the vicinity of Rushford, and between there and Caneadea, the water planes are not conspicuous, it being an illustration of the frequent comparative absence of static-water phenomena in localities where such water is positively known to have existed.

There was no great difference in altitude between the levels of the Rushford lake and the fourth-stage Genesee water, but it is probable that the former was somewhat higher and that the Genesee waters never flooded the Rushford valley. At the top of the rock-gorge the kame-moraine dam is partially leveled as by stream floods. This plane has been measured by aneroid on two separate occasions with results 1,533 and 1,548 feet altitude (see page 438).

In the south branch of Caneadea valley still higher levels of an antecedent local glacial lake will probably be found (see page 448).

The morainal lake began when the ice-sheet uncovered the locality and existed during a long period, sufficient to cut down through 200 feet of Portage-Chemung shales; it may have outlived the glacial waters in the river basin.

The Tuscarora morainal lake occupied the valley of the Kishawa creek from some point north of Nunda village to the morainic dam, which still blocks the junction of this valley with the lower Canaseraga valley. The rock-gorge has been referred to on page 429, and is familiar to travelers on the Western New York and Pennsylvania railroad. In the old lake basin the water-planes are very numerous and conspicuous, in that respect being in striking contrast to the Rushford basin. The highest of the Tuscarora levels are not much under the plane of Warren water which buried the region.

The Tuscarora lake did not come into existence until the Warren waters were lowered, and it was probably the latest of the larger morainal lakes in tributary streams.

The Angelica lake was small but interesting, on account of the simplicity of the evidence and the fact that the moraine dam has been eroded until it is now far below the top of the rock-cut (see page 428). The water-planes are clearly seen, one prominent terrace being the site of the village, and a higher one forming a bench above the village.

Wherever a rock-cut occurs in a tributary of the Genesee, the top of which is much higher than the valley bottom above, or upstream, it is reasonable to assume a former ponding of the water or a morainal lake. A large number of such lakes may doubtless be discriminated in the Genesee basin.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 7, PP. 453-558, PLS. 22-24 APRIL 21, 1896

PROCEEDINGS OF THE EIGHTH ANNUAL MEETING, HELD AT PHILADELPHIA, DECEMBER 26, 27 AND 28, 1895

HERMAN LEROY FAIRCHILD, *Secretary*

CONTENTS

SESSION OF THURSDAY, DECEMBER 26

The Society was called to order at 2 o'clock p m, in room 104, Department of Arts, University of Pennsylvania, President N. S. Shaler in the chair. The President made a few remarks of salutation, and introduced the administrative business of the meeting by a call for the report of the Council. This was submitted in print by the Secretary and copies were distributed to the Fellows.

REPORT OF THE COUNCIL

To the Geological Society of America, in Eighth Annual Meeting assembled:

The Council has held its stated meetings during the past year, in connection with the meetings of the Society, at Baltimore and at Springfield. The affairs of the Society are in good condition, and the Council has no special business or recommendations to present. The following reports of the officers will give detailed information of the past year's administration:

Secretary's Report

To the Council of the Geological Society of America:

Membership.—During the past year the Society has lost four Fellows by death. Past President James D. Dana died April 14, Professor Henry B. Nason died January 17, Dr Albert E. Foote died October 10, and Senor Antonio del Castillo died October 28.

The last printed roll of membership bears the names of 223 living and thirteen deceased Fellows. At the Springfield meeting eleven persons were elected, and all but one have qualified, as follows: S. P. Baldwin, O. C. Farrington, G. P. Grimsley, F. P. Gulliver, J. B. Hatcher, E. B. Mathews, J. C. Merriam, F. L. Ransome, Charles Schuchert, J. A. Taff. Six Fellows have been dropped from the roll for non-payment of dues, and one resignation has been accepted. Nine Fellows are now so in arrears for dues that they are liable to be dropped from the roll. Seven candidates for Fellowship are before the Society.

Distribution of Bulletin.—A comparison of the following report with last year's report will give the details for the past year:

DISTRIBUTION OF BULLETIN FROM THE SECRETARY'S OFFICE DURING 1891–1895

Complete Volumes

	Vol. 1.	Vol. 2.	Vol. 3.	Vol. 4.	Vol. 5.	Vol. 6.
In reserve	73	318	361 (?)	364 (?)	353	109 (?)
Donated to institutions ("exchanges")	85	85	85	85	85	85
Held for "exchanges"	9	9	9	9	9	9
Sold to libraries	72	73	72	69	67	70
Sold to Fellows	17	14	8	5	3	1
Sent to Fellows to supply deficiencies	2	1	1	....	....	....
Donated	4	4	3	2	1	1
Bound for office use	2	2	2	2	2	2
Distributed to Fellows in brochures as issued	..	....	209	214	214	223
Number of complete copies received	264	506	750 (?)	750 (?)	734	500 (?)

Brochures

	Vol. 1.	Vol. 2.	Vol. 3.	Vol. 4.	Vol. 5.	Vol. 6.
Sent to Fellows to supply deficiencies	46	123	42	41	23	3
Sent to libraries to supply deficiencies	..	7	4	3	....	....
Sold to Fellows	12	17	3	12	15	5
Sold to the public	11	11	9	9	4	1
Donated	3	3	3	3	2	....

Subscriptions.—The present number of regular subscribers to the Bulletin is 59, of whom 24 receive the brochures and 35 the completed volumes. During the year two "Exchanges" have become subscribers, two subscriptions have been suspended, and four new subscriptions have been added to the list. The special orders are included in the following table.

Bulletin sales.—The receipts from the sale of the Bulletin during the year amount to $461.50.

RECEIPTS FROM SALE OF BULLETIN DURING 1895

By Sale of Complete Volumes

	Vol. 1.	Vol. 2.	Vol. 3.	Vol. 4.	Vol. 5.	Vol. 6.	Total.	
From Fellows	$9 00	$4 50	$4 00	$7 00	$4 00	$4 00	$32 50	
From libraries	20 00	20 00	25 00	25 00	25 00	265 00	380 00	
Total for 1895	29 00	24 50	29 00	32 00	29 00	269 00	412 50	
By last report (1894)	387 60	384 50	355 50	320 50	298 00	35 00	1,781 10	
Total to date	$416 60	$409 00	$384 50	$352 50	$327 00	$304 00		$2,193 60

By Sale of Brochures

	Vol. 1.	Vol. 2.	Vol. 3.	Vol. 4.	Vol. 5.	Vol. 6.	Total.	
From Fellows	$2 45	$1 55	$0 35	$0 70	$2 75	$2 25	$10 05	
From the public	0 40	2 05	1 50	....	....	....	3 95	
Total for 1895	2 85	3 60	1 85	0 70	2 75	2 25	14 00	
By last report (1894)	18 05	13 00	4 00	4 85	1 15	....	41 05	
Total to date	$20 90	$16 60	$5 85	$5 55	$3 90	$2 25		$55 05

Grand total	$2,248 65
Received for volume 7 in advance	35 00
Total receipts to date	$2,283 65
Amount charged and uncollected	131 90
Total Bulletin sales to date	$2,415 55

Exchanges.—The list of institutions to which the Bulletin is donated now numbers 85, of whom 10 receive brochures and 75 the completed volume. Since the printing of this list, in connection with the list of the library at the end of volume 6, the following changes have been made: Library of University of Toronto and Library of McGill University have become subscribers; Engineering and Mining Journal removed from the list; Museo de la Plata, Geographical Society of Finland, Geological Survey of Sweden, Cincinnati Society of Natural History, National Geographic Society, and American Geographical Society added to the list.

Library.—The books, pamphlets and maps belonging to the Society are deposited with the Case Library, Cleveland, Ohio, under a contract which was outlined in the Secretary's report of last year. The list of material deposited up to January, 1895, is printed in the Bulletin, volume 6, pp. 501–516. The list of material deposited during the present year should be printed in volume 7.

The library is available for the use of the Fellows under the following rules:

1. Fellows are permitted to draw out material in reasonable quantity for a period not exceeding two months.
2. The transportation charges both ways and other expenses are to be paid by the Fellow so borrowing.
3. The Fellow is held responsible only for such loss or damage as may occur through his fault, as, for example, by insufficient wrapping or misdirections.

EXPENDITURE OF SECRETARY'S OFFICE FOR THE SOCIETY'S FISCAL YEAR, NOVEMBER 30, 1894, TO NOVEMBER 30, 1895

Account of Administration

Postage	$36 70	
Expressage	4 77	
Stationery and records	4 95	
Printing, including stationery	105 61	
Meetings	17 50	
Library	20 88	
Total		$190 41

Account of Bulletin

Postage	$91 76	
Expressage and freight	59 49	
Wrapping (envelopes)	18 07	
Collection of checks	1 97	
Total		$171 29
Total expenditure		$361 70

All of which is respectfully submitted.

H. L. Fairchild,
Secretary.

Rochester, New York, *December 21, 1895.*

Treasurer's Report

To the Council of the Geological Society of America:

In submitting the following detailed report of the Society's financial operations for the past year, the Treasurer would add that the names of six members have disappeared from the roll for non-payment of dues, nine others are delinquent for two years and will drop out January 1, while twenty are delinquent for the present year, and three members have resigned; two (Miss Bascom and Mr Baldwin) have commuted for life, and the proceeds ($200), along with Mr Iddings life commutation of last year, have been invested in three bonds of the Kingwood, Tunnelton and Fairchance Railroad Company, bearing 6 per cent interest, payable semi-annually. This makes the Publication Fund of the Society $2,900, upon which it realizes $168 interest annually, in addition to $100 certificate of deposit in Bank of Monongahela Valley, upon which interest at 3 per cent is paid.

RECEIPTS

The receipts from all sources have been as follows:

Balance in the Treasury November 30, 1894		$462 96
Fellowship fees, 1893, 2	$20 00	
" " 1894, 10	100 00	
" " 1895, 179	1,790 00	
" " 1896, 1	10 00	
		1,920 00
Initiation fees, 15		150 00
Life commutations, 2		190 00
Interest on investments:		
Tioga township, Kansas, bonds	70 00	
Cosmos Club bonds	80 00	
Kingwood, Tunnelton and Fairchance railroad bonds	12 00	
Time deposits, Rochester Bank	8 06	
		170 06
Sales of publications:		
Deposited with Security Trust Company, Rochester		491 50
Assessments, cost of publication:		
On account of illustrations	50 00	
On account of correction of proofs	27 50	
		77 50
Total receipts		$3,462 02

EXPENDITURES

The expenditures and disbursements of the funds of the Society have been as follows:

Expenses of Secretary's office:	
H. L. Fairchild, Secretary	$572 49
Expenses of Editor's office:	
J. Stanley-Brown, Editor	160 00

Publication of Bulletin:			
Printing account:			
Judd & Detweiler	$1,364 88		
Engraving account:			
Moss Engraving Co	10 00		
Maurice Joyce Eng. Co	211 47		
		$1,586 35	
Printing account, circulars, etcetera:			
Rochester Democrat and Chronicle		103 51	
Photograph account:			
J. S. Diller		12 22	
Investment account:			
3 bonds of Kingwood, Tunnelton and Fairchance railroad, $100 each, cost		304 00	
			$2,738 57
Balance of cash in treasury November 30, 1895			$723 45

The invested funds of the Society are as follows:

On account of Publication Fund:		
April 1, 1891, one Tioga township, Kansas, bond, cost $1,140.26	$1,000 00	
January 29, 1892, eight 5 per cent Cosmos Club bonds at par, cost $800	800 00	
February 26, 1892, one 5 per cent Cosmos Club bond, with accrued interest, cost $100.35	100 00	
February 3, 1893, seven 5 per cent Cosmos Club bonds at par, cost $700	700 00	
May 1, 1895, two 10-20 gold bonds of Kingwood, Tunnelton and Fairchance railroad, bearing interest from January 1, 1895, cost $204	$200 00	
September 27, 1895, one bond of Kingwood, Tunnelton and Fairchance railroad, with interest from July 1, 1895, cost $100	100 00	
		$2,900 00
November 30, 1894, time deposit in Bank of Monongahela Valley, Morgantown, West Virginia		100 00
		$3,000 00

Respectfully submitted.

I. C. White,
Treasurer.

Morgantown, W. Va., *December 18, 1895.*

Editor's Report

To the Council of the Geological Society of America:

The editorial experience of the past three years has clearly demonstrated that prompt publication is appreciated and desired by the members of the Society. In so far as possible, there should be close adherence to the rule that all the accepted papers of the summer meeting be put through the press before December 30, and that the issue of the accepted manuscripts of the winter session be completed not later than April 30. Although this was practically accomplished in the case of volumes 5 and 6, it was at the expense at times of much editorial haste and effort. The Editor can be relieved of some of this undesirable hurrying by a little more coöperation on the part of members in the way of prompt transmittal of "copy." In response to editorial suggestion it has become the common practice to furnish neat, typewritten manuscripts and suitable tables of contents, thereby greatly facilitating work, promoting accuracy, and aiding economy; and if, now, the importance of promptness can be fully realized by those who contemplate publishing papers, there will be little left to be desired.

At the risk of transgressing editorial privilege the Editor begs leave to call attention to the desirability of conciseness of statement in preparing material for publication in the Bulletin. Carried away by commendable enthusiasm for their subject and earnestly desiring to leave no conclusion misunderstood or unbuttressed by a wealth of evidence, authors unintentionally commit the sin of verboseness. It is rare to receive a manuscript which would not be improved by more or less condensation. The most serious phase of this is that it entails the printing each year of from 50 to 100 pages of needless words, with the resulting exclusion of authors through lack of space.

In addition to the Proceedings brochure, five papers of the summer meeting, several of which are unusually long, were accepted by the Publication Committee. They will make in all about 260 printed pages, requiring some 14 plates and many text figures to illustrate them. They are all in type, with one exception, and probably this manuscript will be in the printers' hands before the close of the month.

The cost of each of the six volumes thus far issued by the Society is as follows:

	Vol. 1. (pp. 593; pls. 13)	Vol 2. (pp. 662; pls. 23)	Vol. 3. (pp. 541; pls. 10)	Vol. 4. (pp. 458; pls. 10)	Vol. 5. (pp. 665; pls. 21)	Vol. 6. (pp. 528; pls. 27)
Letter-press......	$1,473 77	$1,992 52	$1,535 59	$1,286 39	$1,887 21	$1,341 93
Illustrations......	291 85	463 65	383 35	173 25	178 40	221 62
	$1,765 62	$2,456 17	$1,918 94	$1,459 64	$2,065 61	$1,563 55*

It will be noted that volume 6 is relatively the cheapest ever issued by the Society, in spite of the unusually large number of plates. This saving is due to the revision of the printing contract and the reduction of the edition from 780 to 530.

Respectfully submitted. JOSEPH STANLEY-BROWN,

WASHINGTON, D. C., *December 20, 1895.* *Editor.*

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* From this sum should be deducted $77.50, being members' contributions for illustrations and correction charges.

Upon motion of the Secretary, it was voted to lay the Council's report upon the table until Friday morning.

As the Auditing Committee to examine the accounts of the Treasurer the Society elected Frank Leverett and Jed Hotchkiss.

ELECTION OF OFFICERS

The result of the balloting for officers for 1896, as canvassed by the Council, was announced by the Secretary, and officers were declared elected as follows:

President:

JOSEPH LE CONTE, Berkeley, Cal.

First Vice-President:

CHARLES H. HITCHCOCK, Hanover, N. H.

Second Vice-President:

EDWARD ORTON, Columbus, O.

Secretary:

H. L. FAIRCHILD, Rochester, N. Y.

Treasurer:

I. C. WHITE, Morgantown, W. Va.

Editor:

J. STANLEY-BROWN, Washington, D. C.

Councillors (term expires 1898):

B. K. EMERSON, Amherst, Mass.
J. M. SAFFORD, Nashville, Tenn.

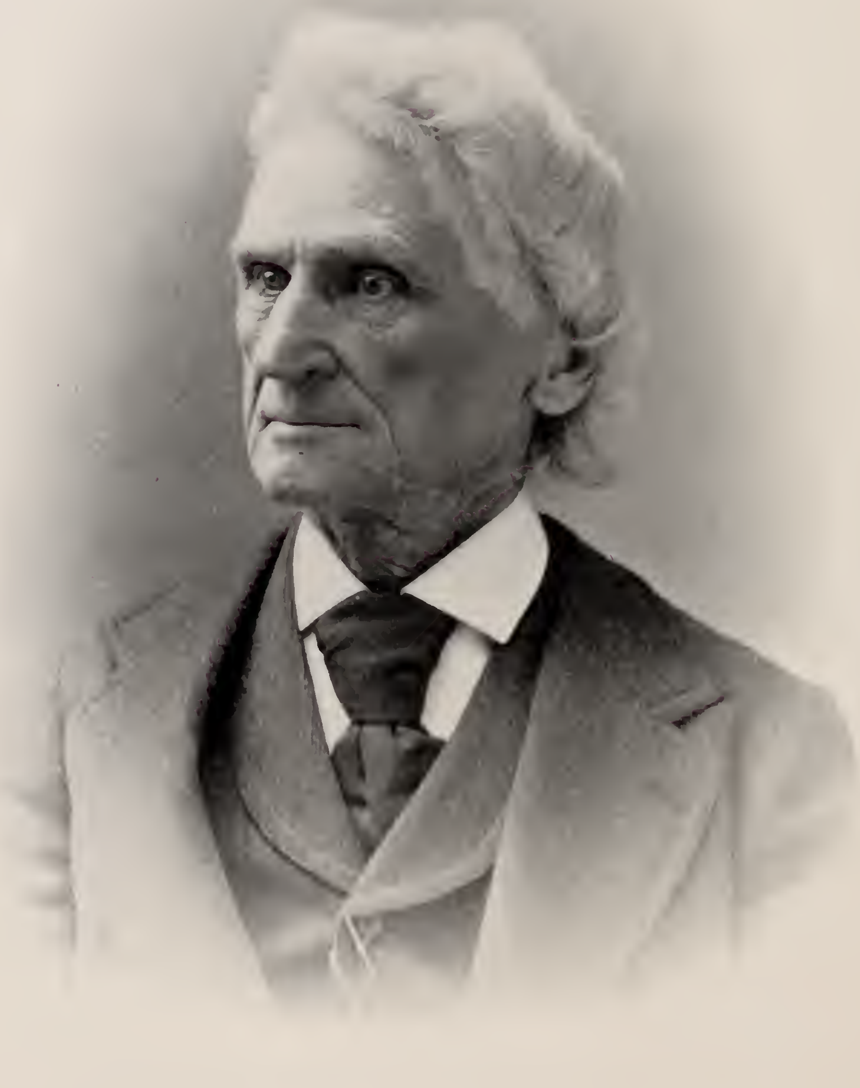
ELECTION OF FELLOWS

The result of the balloting for Fellows, as canvassed by the Council, was announced, and the following persons were declared elected Fellows of the Society:

HARRY FOSTER BAIN, M. S., Des Moines, Iowa. Assistant Geologist Iowa Geological Survey.

WILLIAM KEITH BROOKS, Ph. D., Baltimore, Maryland. Professor of Zoölogy in Johns Hopkins University.

CHARLES ROCHESTER EASTMAN, A. M., Ph. D., Cambridge, Massachusetts. Assistant in Paleontology in Museum of Comparative Zoölogy, and in Harvard University.



James D. Dana

Henry Barnard Kümmel, A. M., Ph. D., Trenton, New Jersey. Assistant on the State Geological Survey of New Jersey.

William Harmon Norton, M. A., Mount Vernon, Iowa. Professor of Geology in Cornell College.

Frank Bursey Taylor, Fort Wayne, Indiana.

Jay Backus Woodworth, B. S., Cambridge, Massachusetts. Instructor in Harvard University and Assistant Geologist on U. S. Geological Survey.

The President then called for the reading of biographic sketches of Fellows who had died during the year. In the absence of Professor Le Conte, the following memoir of Professor Dana was read by H. S. Williams:

MEMOIR OF JAMES DWIGHT DANA

BY JOSEPH LE CONTE

In the death of Professor Dana, the foremost geologist of America and one of the foremost in the world has been taken from us. I am sure the Geological Society will pardon me if I introduce this notice of him with some personal reminiscences.

The first meeting of the American Association for the Advancement of Science that I ever attended was the New Haven meeting in 1850. Professor Dana read a short paper "On the Analogy, in Reproduction, between the Hydroids and Plants," showing how the nutritive individuals and the reproductive individuals of the one correspond to the leaf-individuals and flower-individuals of the other. His slender, erect form, his sharp, clear-cut features and penetrating eyes, his eager face and noble head crowned with abundant and somewhat disheveled hair, and, above all, the combination of philosophic thought and poetic imagination embodied in the paper, made an indelible impression on me—an impression which has only deepened with time. The leaders in American science at that time were such men as Agassiz, Pierce, Henry, Bache, William and Henry Rogers, Gray, and Hall—surely as brilliant a constellation of first magnitude stars as any since that time. Among such men Dana, although only thirty-seven years old, was even then a prominent figure, for had he not already published his great work on mineralogy and his grand researches on the zoophytes, the crustacea and the geology of the United States Exploring Expedition?

I next saw Dana and again heard him at Albany, in 1856, when he read his address as retiring president of the Association. In this address he brought forward again (for he had already done so nearly ten years earlier) his grand views on the development of the earth in its larger features. May we not say that geology as a distinct science, having its own fundamental idea, namely, that of the evolution of the earth through all time, had its birth in these early papers of Dana, commencing as far back as 1847, when he was but thirty-three years of age. If with Comte we define a great life as one in which a noble idea conceived in youth is persistently carried out and perfected to the end, then was Dana's indeed a great life; for this, the fundamental idea of geology, was clearly conceived by him in early life and elaborated in all its details to the very end. It was moreover a noble idea, for by it the science of geology was vitalized into a higher life. Let me stop a moment to inforce this point.

Those who are familiar with Comte's "Positive Philosophy" will remember that in his "Hierarchy of the Sciences" he denies geology a place. He does so on the ground that it is not an abstract science at all, but is, like geography, only a field for the operation of all the sciences. Every distinct science has its own fundamental idea and its own distinctive method. Thus mathematics has its own fundamental idea of number and quantity and its own distinctive method of notation. Physics and chemistry their fundamental ideas of mechanical energy and chemical affinity and their distinctive method of experiment. Biology its characteristic idea of life and its distinctive method—"the method of comparison." Sociology its characteristic idea of social organization and its distinctive method—"the historic method." But according to Comte geology has neither characteristic idea nor distinctive method of its own. I have long ago* shown the mistakes of Comte in this regard. Geology also has its own characteristic underlying idea and that the grandest of all, namely, that of *evolution of the earth through all time;* and its own distinctive method, the *evolution* method or comparison in the evolution series. The idea of evolution was not yet clearly grasped by science at that time, otherwise Comte would have seen that his historic method is naught else than the evolution method imported from geology into sociology.

Now this fundamental idea of geology and this distinctive method, although indeed dimly seen by previous thinkers and expressed by previous philosophical writers, especially by Whewell in his "Philosophy of the Inductive Sciences," had not become a vitalizing idea and a working method until Dana. This was the underlying idea and this the working method of all his work, and they were both finally embodied in that really wonderful book, his "Manual of Geology." I regard Dana's work as forming a distinct and very important epoch in the history of geological science. Modern geology has two important epochs—that of Lyell by the introduction of the study of "causes now in operation" as the only sound basis of induction, and that of Dana by the introduction of the idea of the development of the earth as a whole through all geo-

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* Comte's Classification of the Sciences, Berkeley Quarterly, April, 1881.

logical time. The idea of study of "causes now in operation" as the basis of induction in geology had been indeed introduced before Lyell, especially by Hutton and Playfair, but Lyell first thoroughly and systematically used it and constructed a geological science upon it. So also the idea of development of the earth was conceived before Dana, but Dana first reconstructed geological science on this basis. As long as the Lyellian idea of geology prevailed, the philosophic classifiers of the sciences were justified in regarding it as a mere field for the application of physics, chemistry and biology. Geology became one of the great departments of abstract science with its own characteristic idea and its own distinctive method under Dana. This I know is putting Dana on a very high pedestal, but I am quite sure he deserves that position.

The history of his life has already been presented by one far more competent to do so than I—his own distinguished son. It is therefore wholly unnecessary to give any extended account. Nevertheless, for the sake of completeness and for the information of those who have not seen the memoir referred to, I take from it the main points of his life.

He was born at Utica, New York, February 12, 1813, of intelligent New England parents, and died in New Haven, Connecticut, April 14, 1895, having therefore reached the great age of eighty-two years and two months. His early taste for science was fostered, and the right method in its pursuit—that is, by direct contact with nature—was taught him by the example of his early teachers. In 1830 he entered Yale College, where his scientific activity was still farther stimulated by intimate association with the elder Silliman, then in the zenith of his reputation. Immediately on completing his college course in August, 1833, he entered on a voyage of fifteen months as instructor in mathematics of the midshipmen of the United States navy. In this capacity he visited many points in and about the Mediterranean and took advantage of this opportunity to study the phenomena of volcanoes, and his first paper, published in Silliman's journal in 1835, was on Vesuvius. Thus early were his thoughts turned on interior earth forces. On returning he became an assistant in chemistry to Silliman. In 1838 the United States Government sent out an exploring expedition to circumnavigate the earth. On this Dana was appointed naturalist. The fleet of five ships sailed in August, 1838, and returned to New York in June, 1842, after an absence of nearly four years. The scientific fruits of this famous expedition will be discussed later.

With the exception of these two voyages, Dana's life, like those of most scientific men, was uneventful in the ordinary sense. His activity and his achievements were almost wholly in the field of thought; but there his activity in original work was incessant for over sixty years. There were few departments of science that he did not touch, and whatever he touched he illuminated. An orderly method of work, economic of time and conservative of energy, enabled him to do an almost incredible amount in spite of an exceptionally delicate frame and precarious health, which repeatedly broke down completely under the strain of ceaseless work.

After returning in 1842 from his memorable voyage, with the exception of two years, 1842–1844, spent in Washington, D. C., while preparing his reports as naturalist, and one year, 1859–1860, in Europe, recruiting his broken health, and a summer vacation in 1887 spent in the Hawaiian islands to renew his acquaintance with the volcanoes and observe what changes had been wrought by time—with these exceptions he lived in New Haven, engaged in teaching and in original work.

There are few, very few, men (and becoming fewer every year) whose thoughts ranged so widely and who accomplished distinguished results in so many directions as did Dana. He became the highest living authority in mineralogy, in several departments of zoölogy—as, for example, crustacea and zoophytes—and more than all in geology. Of some two hundred and odd scientific papers contributed by him, more than one-half were on geology. Not only in the three sciences mentioned above was he in the foremost rank, but in other sciences also—as, for example, physics, chemistry and even mathematics—his knowledge was wide and exact. As he grew older, however, his chief interest and highest activity gravitated more and more toward geology. This was the natural result of the wide sweep of his mind, for geology is the most complex and comprehensive of all the sciences. All other sciences are tributary to her. It was for this reason in part that early philosophers of science regarded her as only an applied science—as a field for the application of all the sciences. Dana's wide and exact knowledge in many departments fitted him in a peculiar way and in an eminent degree for the highest achievements in geology. No mere specialist in geology could have done Dana's work.

Leaving out of view his monumental work on mineralogy, for the reason that others are more capable than I of weighing its value, there are three main lines of thought, all suggested by his observations during his four years' voyage, which occupied his mind throughout life.

The first of these was corals, coral reefs and coral islands. This is a subject of deepest interest, both popular and scientific; popular on account of the gorgeous coloring and the delicate flower-like beauty of the zoophytes and the gem-like, fairy-like beauty of the islands formed by them—a beauty which has so affected the imagination of artists as to have given rise to a peculiar South Sea literature which reads like fairy literature; it is of equal or even greater scientific interest because of the infinite variety of life-forms crowded together on the reefs, making them a veritable zoölogical garden, the greatest gathering-ground of the naturalist and the greatest theater of the struggle for life to be found anywhere on earth. But more than all to the geologist are they of deepest interest on account of the evidence they afford of movements of the crust of the earth on a scale of grandeur commensurate with the formation of those greatest features of the earth-surface, continental areas and oceanic basins. The subsidence theory of atolls and barriers powerfully affected the mind of Dana, and, although it originated with Darwin, no one, not even Darwin himself, has done more by close observation and wide generalization to establish it on a solid foundation. It is true that as a universal theory, at least for barriers, it can no longer be maintained, having been disproved by the observations of Agassiz on the coast of Florida, but as a general theory, on which may be based the conclusions drawn from it by Darwin and Dana, that the floor of the mid-Pacific over an enormous area is sinking and has been sinking for ages, I believe it still holds its own as by far the most probable theory. Correlative with this sinking is the rising of the American continents, especially on their western side.

The second line of thought suggested by the observations of his famous voyage, but which he continued to follow up during his whole life, was the idea of cephalization or headward development; that is, the increasing dominance of head functions over other functions, and therefore the increasing subordination of the whole structure of the animal body to the service of the head as we go up the scale in any class. Dana announced this as a law of structural elevation in any class, or, as we would say now, as a law of evolution, and therefore as a guide to classification. He came upon this law in studying the modifications of the limbs of crustaceans. He found that as we rise in the scale more and more of the appendages are released from the function of locomotion to be devoted to the service of the head. He afterwards applied it to other classes of animals. Like all great thoughts, its fertility is inexhaustible and its application boundless. It might be generalized as a gradually increasing dominance of the higher over the lower and of the highest over all. In this form the law is universal. To give one illustration of my own: In passing from the lowest protozoan to man, among the many systems of organs which are successively differentiated there is an increasing dominance of the highest system, namely, the nervous system. Then in the nervous system an increasing dominance of the highest part, that is the brain. In the brain an increasing dominance of the highest ganglion—the cerebrum. In the cerebrum of the highest part, namely, the external gray matter as shown by the number and depth of the convolutions. Then among the convolutions an increasing proportion in the highest lobe of the cerebrum—the frontal lobe as marked off by the fissure of Roland. I need hardly say that the same law prevails also in the evolution of the individual, both physical and psychical. As there is an increasing dominance of mind over body, so in the mind there is an increasing dominance of reflective over the perceptive faculties, and finally of the moral faculties over all. The same is true of social evolution. In all and everywhere we find the same law of cephalization. Everywhere—in physical, psychical and social evolution; in education, in intellectual and moral culture, and in civilization—we find an increasing dominance of the higher over the lower and of the highest over all.

I do not follow up this thought only because I do not know that Dana himself did so. In a singular degree he united boldness of thought with extreme cautiousness in method.

The third line of thought suggested to his mind by his famous voyage was that of volcanism. Early in life, during his Mediterranean voyage, he became interested in this subject, as shown by his paper on Vesuvius, the first he ever published, but his interest was greatly quickened and broadened by the study of volcanic phenomena in the south seas, especially in the Hawaiian islands. In accordance with the abounding fertility of his thought, he now no longer confined himself to simple local volcanism, but connected this with all other forms of igneous agency, and especially with those grander movements of the earth crust which determine the greater features of the earth's surface. These movements, though so slow and inconspicuous as to be unperceived except by the ever watchful eye of science, yet, extending over wide areas and acting through inconceivable time, their accumulated effects far surpass all other forms. Indeed volcanic eruptions and earthquake shocks are but occasional accidents in the slow march of these grander movements.

Thus it is in all things, the really most potent causes are slow in operation and inconspicuous in their effects and are therefore recognized only by the scientific thinker. For example, railroad accidents and steamboat disasters, plague and pestilence, strike the popular imagination and fill the mind with horror, while the slower but constantly acting effects of dyspepsia and consumption, which destroy their thousands for one carried off by the more catastrophic way, hardly attract attention enough to enforce their remedy by improved sanitary conditions. Similarly wars and revolutions strike the popular imagination and fill the pages of history, while the slow approaches of political corruption and decay of truthfulness which poison the lifeblood and sap the vitality of nations are hardly regarded. Even so volcanoes and earthquakes strike the imagination and fill the pages of geological literature, while the slowly accumulating and far grander effects of crust oscillations hardly arrest attention; and yet it is by these alone that continents and ocean basins have been gradually formed.

Now it was just these slowly acting causes and these grander effects that took strongest hold on Dana's mind. Igneous agencies became for him the interior vital forces of the earth, which, reacting on the exterior crust, produced the greater features, and by their eternal conflict with external, sun-derived, sculpturing forces determine the evolution of the earth as a whole.

The mention of this line of his thought introduces us naturally to the next head, and that the one which most deeply interests this Society, namely, Dana as a geologist.

Professor H. S. Williams has already given an admirable account of this in the Journal of Geology for September, 1895. I am indebted to him for much that follows. For other details I would refer the reader to that article.

As already said, the idea underlying all Dana's geological work is that of development of the earth as a unit. Before Dana, geology was doubtless in some sense a history—that is, a chronicle of interesting events; but with Dana it became much more, it became a philosophic history, a life history, a history of the evolution of the earth, and of the organic kingdom in connection with one another. For the first time there was recognized a time-cosmos governed by law as the true field of geology, as the space-cosmos governed by law is the field of astronomy. Before Dana, geology was the study of a succession of formations; with Dana it was the study of a succession of eras, periods, epochs during which geographic forms and organic forms were both developing toward a definite goal. The underlying idea of his geological work, I repeat, was the evolution of the earth as a whole.

It is necessary to stop a moment here to qualify and explain. It is true that he made a difference between the evolution of the earth and that of the organic kingdom. It is true that while the development of the earth was regarded by him as a natural process and determined by natural causes, and therefore a true evolution, at first and for a long time he regarded the progress of the organic kingdom as belonging to a different category, as not an evolution in the true sense of the word—that is, not as a wholly natural process determined by natural forces residing in the thing evolving. Like Agassiz, he preferred to liken the development of the organic kingdom to the building of a temple under the intelligent plans of an architect outside of the work and acting, as it were, on foreign material, rather than to an egg evolving under its own resident forces. He could not at first see that natural processes are really divine processes, and natural forces are forms of the divine energy resident in nature; yet it is plain to see now that his mind was so saturated with the idea of evolution and his mode of thought so determined by evolution methods that he was bound by philosophic consistency to reach eventually a true evolution point of view in the case of the organic kingdom as well as in that of the earth.

Let me, however, in passing do justice to Agassiz, for in doing so I do justice also to Dana for embracing his views.

There can be no doubt that Agassiz prepared the way for the theory of evolution of the organic kingdom, and even laid its whole foundation, in the three great laws of succession of organic forms on the earth. These are: (1) The *law of differentiation* of specialized from generalized forms. These early generalized forms he called synthetic types, combining types, prophetic types. (2) The law of *successive culmination* of higher and higher dominant classes. This was embodied in his idea of successive reigns. (3) The law of *progress of the whole*, though not necessarily of all the parts. These three laws of succession of organic forms are literally the formal laws of phylogeny and therefore of evolution. It only remained to reduce these formal laws of succession to a natural process. This Darwin did. Upon no other foundation could a solid structure have been raised. Without Agassiz, Darwin could not have been.

Now, Dana cordially adopted Agassiz's view of the development of the organic kingdom. By its grandeur and comprehensiveness it both captivated his mind and satisfied his religious nature, but in his own peculiar field, namely, that of development of earth-features, he always spoke only of natural processes and natural causes. Agassiz's strong and dominating nature never yielded to the new doctrine. Even if he had lived to Dana's age, it is probable he would never have adopted the modern acceptation of evolution. Dana's more gentle and plastic nature could not thus set in unchangeable form. His open receptiveness of mind could not close itself to truth, even though it came from unexpected quarters and in unwelcome guise. He finally came to see that the grandeur of Agassiz's views was not lessened by admitting a natural process. In his latest utterances he cordially accepted evolution in its modern sense and as applied to the organic kingdom as not only the truest, but also the noblest view of the process of development. But while he held firmly and expressed clearly this idea of evolution of the whole earth through all time, yet he recognized the impossibility, in the present state of geological knowledge, of carrying it out in detail in every part of the earth. He therefore conceived the idea of taking one best known and simplest continent as a type. He regarded the North American as such a type-continent and its evolution as an epitome of geological history. Undoubtedly in this he was right. In the simplicity of its form and structure and especially in the unity of its development it certainly deserves to be so regarded. To show this unity of development has been the main object of his geological work. As early as 1856 he compared the evolution of the American continent to the development of an egg. From this point of view (to carry out the idea) the Canadian Archean area may be compared to the germinal disc, about which gathered and organized itself the whole continent. This idea of an organic development of the continent he worked out in all its details. Whether we accept all these details or not, the idea has become the working theory not only for American geologists, but for geologists everywhere. There can be no doubt that Dana's ideas and Dana's work, especially as systematically embodied in his Manual, constitutes a distinct epoch in the history of geological science.

Nor did he stop with the formal laws of this development. His active mind could not rest short of inquiries into the causes of these laws; and for this inquiry his accurate knowledge of physics and chemistry admirably fitted him. A very brief outline of his views may be stated as follows:

1. In the secular cooling of the earth from primal incandescent liquid condition the continents mark the places of earliest crust-cooling and consolidation—probably because they were the places of least conductivity and therefore of least transference of heat from within—while contrarily the future ocean basins were determined by the places of greatest conductivity and therefore of most rapid cooling all the way down to the center, and therefore also of most rapid radial contraction. But for that very reason the crusting in these places was later, the surface being kept hot by conduction of heat from below.

2. The more rapid contraction in a radial direction—that is, sinking of the ocean bottoms—not only caused water to accumulate there, but by straightening the curve of the earth-crust pressed against the continents on each side, pushing up their edges and crumpling them into coast ranges, and thus determining the typical form of continents, viz., that of interior continental basins with coast-range rims. He worked out the whole theory of mountain-range formation from this point of view; and if American geologists have been especially active and successful in developing the theory of the formation of mountain ranges, it is because Dana led the way. It is easy to see, therefore, why he was so

intensely interested in the sinking of the mid-Pacific bottom, as indicated by the coral reefs. This sinking had its correlative in the elevation of the western side of the American continents, north and south, and especially in the ridging up of their margins into the great mountains on that side.

In the above statements (1 and 2) I believe I have given substantially Dana's views, although perhaps modified a little by suggestions of my own mind; but we go on.

3. It is evident that from this general point of view the same causes which originated continents and ocean basins, by continuing to act, would increase the size and height of the former and the depth of the latter, and therefore the places of continents and oceans must have remained substantially the same. Dana, therefore, was the originator of the idea of the substantial permanence of the places of these greatest inequalities of the earth's surface. The previous school, which may be called the school of Lyell, took an entirely different view. The gradual evolution of the earth as a unit and of the organic kingdom as a whole was imperfectly, if at all, conceived by the Lyellian school, for Darwin was not yet. Fossils were "medals of creation"—means of determining strata—the oscillations of the earth's crust were irregular and without law or goal; the continents and the oceans had changed places many times in the history of the earth. For Dana, on the contrary, earth-forms have steadily developed toward their present condition. The idea of evolution was clearly conceived and applied to the earth (though not to the organic kingdom) by Dana long before Darwin's time.

Doubtless this idea of permanence of earth-forms may be pressed too far, but was never so pressed by Dana. For him it was not absolute rigid permanence, for that would be contrary to the idea of evolution; for him it was permanence of thought, of plan, but carried out by development, and therefore with many changes in detail. There have doubtless been many oscillations of the earth's crust, many submergences and emergences of land surfaces, especially on the margins, though sometimes of greater extent and affecting also the interior of continents, oscillations the causes of which we do not yet understand, but with these qualifications and limitations the principle is now well established and generally accepted.

4. As a necessary consequence of steady contraction resisted by crust rigidity, there must have been paroxysms of yielding and therefore periods of readjustments of the crust to new positions, and therefore also extensive changes of physical geography and corresponding changes in organic forms. These times Dana appropriately called *revolutions.* They are marked by the formation of great mountain-ranges. The greatest of

these, and the one that Dana first announced, was the "Appalachian revolution," which occurred at the end of the Paleozoic. Other revolutions have been brought out by Dana and by others. The idea has been a most important and fertile one in American geology.

5. Again, it is almost a necessary corollary from the preceding view of the origin of continents and ocean basins by unequal radial contraction, that the sub-ocean crust would be denser in proportion as it has contracted more and the radii shorter, and the continental masses lighter in proportion as they have contracted less, and their radii longer; therefore, also, the continental masses and the sub-oceanic material are in isostatic equilibrium. This idea was originated later by Dutton, but is a necessary result of Dana's views.

I have dwelt on this idea of the development of the earth as a unit because it is the grandest and most original of Dana's ideas and that on which his claims to greatness must mainly rest; but there are also other ideas which, if they did not originate with him, were worked out by him with untiring energy and consummate skill. The most important among these, perhaps, is that of the continental ice-sheet.

We have already spoken of the effect of Agassiz's development-views on Dana. The fact is, there was much in common in the character of the minds of the two men. Both were in a marked degree men of advanced thought and spirit. If Agassiz had the advantage of intenser enthusiasm and perhaps greater genius, Dana had the advantage of wider knowledge of science in many departments and more systematic and orderly methods of work. When Agassiz first brought out his views of the ice-sheet origin of the drift, nearly all geologists, and indeed scientific men generally, regarded them as in the last degree chimerical. Humboldt wrote immediately entreating him as he valued his reputation to reconsider his extravagant views. Dana, on the contrary, at once embraced them with ardor. Now that the contest has ceased and Agassiz's views, pruned of some of their extravagant features, have triumphed, on looking back over the ground the important part that Dana played in this controversy is evident. Many others have contributed largely to the establishing of the fact of the existence of a North American ice-sheet and determining its limits, chief among whom must be mentioned Chamberlin, Upham, Hitchcock, Lewis, Wright, and others; but Dana was their leader, not only in first embracing the idea, but in abundant, painstaking, detail work on the phenomena in New England.

If time permitted we might take up many other subjects which he touched only to illuminate, subjects which in his mode of handling showed that rare combination of original thought and painstaking, detailed work which characterized him in so remarkable a degree. We can barely allude to his work on the vexed "Taconic question" which he, assisted by Walcott and others, contributed so largely to clear up; also to his work on the difficult question of metamorphism, to which he devoted much thought and careful work in the field.

There has been very much talked and written lately on the subject of endowment of research. I strongly sympathize with this movement. I hope the subject will continue to be agitated. We cannot have too much of endowment of research; but it is of the greatest importance that we should not push this idea to the extreme, as some do, of divorcing teaching and research. There can be no doubt that a teacher is all the better teacher for being an investigator. I suppose all will admit this, but it is no less true that an investigator is all the better investigator for being also a teacher, always provided ample time is given him for investigation. There never was a better illustration of this than the case of Dana. The equality of action and reaction is a law of psychics as well as of physics. Verily our pupils and even our children teach us as much as we teach them. Nothing so stimulates the intellectual activity as the coöperative work of a community of interested learners and workers. Nothing so clarifies the thoughts as the earnest attempt to express them clearly to pupils eager to learn, yet prompt to criticise, and, best of all, nothing so systematizes, organizes, unifies our knowledge on any subject as does its conscientious, year-by-year presentation to an intelligent class. Thus and thus only is it possible to make a solid organized body of knowledge which shall form a nucleus about which, by attraction and accretion, must gather additions from all sources. Dana could never have written such a book as his Manual had he not been a life-long teacher.

Now, just such a solid body of systematic knowledge is necessary as a basis of productive original work not only in the systematizer himself, but in all other workers. Not only was Dana's Manual the result of his teaching, but the solid body of organized geological knowledge contained therein formed the basis on which all American geologists, including Dana himself, founded their original work. Just such a solid foundation is necessary as a basis on which the successive stories of the complex structure of geological knowledge must be built.

I repeat, then, that teaching and research are closely allied by the necessities of each and by the structure and laws of activity of the human mind. What God and nature have joined together let no man put asunder. Let me not be misunderstood. I strongly advocate the endowment of research not only in connection with teaching, but also separately. Many kinds of work of the most important kind can only be undertaken by the government. Such, for example, as exploring expeditions, like the voyage of the *Beagle* and the memorable researches of Darwin, the United States exploring expedition and the no less memorable researches of Dana, and the later expeditions of the *Porcupine*, the *Challenger*, the *Blake*, and the *Albatross*, with their brilliant results. In the same category, also, would come great government institutions like the Smithsonian, the National Museum, and the scientific bureaus like the United States Geological Survey, with their army of workers. Doubtless investigations may thus be carried out on a scale impossible for universities. Doubtless many kinds of work could not be undertaken in any other way. Doubtless many investigations may thus be pushed along certain lines much farther than in any other way; but even in these there is no complete divorce of research from teaching. Even here the same law of action and reaction must prevail. Productive work is always conditioned on and proportioned to the communication of results; receiving is conditioned on and in proportion to giving, only in this case the giving is indirect—that is, by publication, instead of direct and personal contact. But no one, I think, will deny the more stimulating effect of the direct, personal relation of the teacher and the taught. Real effective teaching is largely the result of personal magnetism. The communication of scientific spirit and scientific enthusiasm, the contagion of noble thought and high purpose, is even more important than the actual information imparted. That Dana was a great teacher in this higher sense cannot be doubted by any one who knew his clearness of thought and statement, his boundless scientific enthusiasm, and his sincere love of earnest young learners.*

It is impossible, however, even if it were desirable, to separate the teacher from the man, for surely the man himself teaches more and better than all his words. It does not become me to speak at any length on this subject. I dare not enter the inner sanctuary of home and home relations, but what he was there is easily seen by traits of character which were patent to all. No one could be in his company, much less sit under his tuition, without being impressed and charmed with his simple earnestness of character, his ardent love of truth for its own sake, and therefore the perfect truthfulness of his innermost nature In all his writings there appear an open receptiveness of mind, a perfect justness of judgment concerning the work of others, wholly unconditioned by self, and a perfect willingness to modify his own views or even to correct an error. A notable example of this is found in his final acceptance of evolution in

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*For fuller illustrations of this the reader is referred to an article by Farrington. Jour. of Geology, vol. 3, 1895, p. 335.

its full meaning—that is, the "origin of organic forms by descent with modifications"—as the only complete explanation of the phenomena of geological succession, and therefore as the mode of operation of the divine energy in the process of creation.

Our master in geology is taken from us. Let us hope that if his full mantle may not fall on any one, it may at least be parted among us.

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* The following list includes only titles in geology and mineralogy. A full list of Professor Dana's writings, from which this list is extracted, is printed in the *American Journal of Science*, vol. xlix, May, 1895; also in the *American Geologist*, vol. xvii, January, 1896.– H. L. F.

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In the absence of the author, the following memorial was read by Bailey Willis:

MEMOIR OF HENRY BRADFORD NASON

BY T. C. CHAMBERLIN

Professor Henry Bradford Nason, one of the founders of this Society, was born at Foxborough, Massachusetts, June 22, 1831. His boyhood was chiefly passed at North Bridgewater, Massachusetts, the native place of his mother. His early education was secured in a school for boys at

Newburyport, in the Adelphian Academy at Bridgewater and in the Williston Seminary at East Hampton. In 1855 he graduated from Amherst College with high honors. The same year he began a series of travels and studies in Europe, entering Göttingen University in the fall, where he studied chemistry under the distinguished Wöhler, with mineralogy and geology as collateral studies and physics and botany as accessory ones. His vacations were given to travel in various parts of Europe. Receiving the degree of Ph. D. in 1857, he spent some further time in travel before his return to this country. The following year he taught in the Raymond Collegiate Institute and in the succeeding year was appointed Professor of Natural History in that institution. In the same year he was chosen Professor of Chemistry and Natural History in Beloit College, a position which he accepted and continued to occupy until 1866, when he resigned it to accept a professorship in the same departments in Rensselaer Polytechnic Institute, which he held until the time of his death, January 18, 1895.

Besides the degree of doctor of philosophy which he earned at Göttingen, he received the honorary degree of M. D. from Union College and that of LL. D. from Beloit College, and was honored by membership in many societies, scientific, industrial and social.

Professor Nason was a very wide and observant traveler, and much of the breadth and catholicity of sympathy, which were signal elements of his character, was doubtless derived from his wide contact with both humanity and nature. In addition to what has already been indicated, he spent portions of the years of 1861, 1877, 1878 and 1884 in Europe, his travels ranging from Norway and Finland to the Mediterranean, and his subjects of study from the glaciers of the first to the volcanoes of the last. He was one of the jurors of the Paris Exposition of 1878 in the department of mineralogy and metallurgy. In this country he traveled extensively in the south and made repeated trips to the Pacific coast, while for eight years he divided his time as a teacher between the east and the interior. His instruction was greatly enriched from the large fund of personal knowledge and experience thus acquired. The writer remembers vividly, across the lapse of nearly thirty years, many illustrations drawn from the great treasure-house of his personal observation.

Professor Nason was primarily a chemist and mineralogist, and it is not appropriate to this place to dwell in detail upon this phase of his work, even though it was the central one. His merits as a chemist will receive due recognition from his colleagues. It is pleasant to note, however, in passing, that he was chosen a member of several of the foreign as well as of the leading American chemical societies, and that he was the editor of several chemical and mineralogical works.

It was not his main work, but the breadth of his scientific interest and the general esteem in which he was held, that led to his connection with this Society as one of its initial members. His special geological interest lay in the lines of volcanic phenomena which he studied in southern Europe. His too great modesty, however, withheld him from publication in a department not primarily his own. His geological studies were therefore chiefly serviceable as a source of personal culture and a basis of instruction.

He taught geology for many years, and it was the privilege of the writer to be one of his pupils nearly thirty years ago. Coming to the subject as a required study without enthusiasm and with a theological prejudice that would fain have found it all a fallacy, he was so led about by the fairness and frankness of Professor Nason's catholicity and by the irrefragable evidence which his personal observations brought into play to support the doctrines of the text that the life-interest of the pupil was turned into a wholly unexpected channel.

As a teacher, Professor Nason was an expositor rather than a drill-master. His aim was to set forth the truth in its fairest light and leave it to win its own way, and the gentleness and grace of his exposition doubtless often won when forceful argumentation or zealous propagandism would have failed.

Professor Nason was a man of singular gentleness and refinement of character. He possessed the esteem and affection of his associates in all relations of life in a very unusual degree. Students, faculty, citizens and scientific acquaintances alike entertained for him an exceptional regard as a man, a citizen and a scientist. His memory will remain with all as one of singular sweetness.

The following memorial was read by J. F. Kemp in the absence of the author:

MEMOIR OF ALBERT E. FOOTE

BY GEORGE F. KUNZ

The recent death of Professor Albert E. Foote, which occurred on the 10th of October, at Atlanta, Georgia, after a five days' illness, and just on the eve of a Florida trip, has removed from among us one of the most widely known representatives of the science of mineralogy on this continent, and it is eminently fitting that some formal reference to his life and work should be made.

Dr Foote was born at Hamilton, Madison county, New York, in 1846; he came of early Massachusetts stock, and some of his ancestors earned fame in the American revolution. He studied at Cortland Academy, Homer, New York, and entered the class of 1867 at the University of Michigan, where he graduated with the degree of M. D. His interest in science began while at Cortland Academy, where he formed the acquaintance of Dr Caleb Green, and became through him deeply interested in natural history, especially in geology and mineralogy. Many days were spent by young Foote in excursions with Dr Green to points of scientific interest in the neighboring districts of central New York. The tastes thus developed led him on to his life-work. On graduating at Michigan University he had won so high a rank in his scientific studies that he was chosen out of a large class as an assistant in the University laboratory. From this position he was called in a year to an assistant professorship of chemistry in the Iowa Agricultural College at Ames, Iowa. Here he remained as a successful instructor for several years, with the exception of one year spent in Europe, under leave of absence, when he studied chemistry and mineralogy with the celebrated Hoffman in Berlin. In 1873 he visited Arkansas and brought to New York the first great quantities of arkansite, nigrine, wavellite, quartz and other minerals, and made a private exhibit in the arsenal at Central Park.

In 1875 he removed east and came to reside in Philadelphia. Here he organized his first public exhibition of minerals, for the Centennial Exposition of 1876, and has since made similar displays at nearly all the great exhibitions of the world, for which he received many medals and awards. At the time of his death he had charge of the mineralogical exhibit of Pennsylvania at Atlanta. He was accustomed to go south in winter, as for twelve years he had suffered with pulmonary consumption, but it was not supposed that his end was by any means near.

Professor Foote, as we all know, was prominent not so much in pure science as in the dissemination and extension of scientific interest; he was not specially an author of books, an investigator in the laboratory, or a lecturer before public audiences, neither was he a great private collector and amateur; yet in his own line of work he combined many of these forms of influence, and has given an impetus and a status to mineralogy in America such as hardly any other man has been able to do.

After leaving his professorship of chemistry in the Iowa Agricultural College, he turned his attention to mineralogy as a business, and began a system of collecting, exchanging, advertising and sale of well selected and accurately labeled specimens that has made his name a "household word" among all mineralogists in this country during the past twenty years and widely known abroad. For this kind of work he was remarkably qualified; he had the scientific knowledge and the business capacity alike needed; he possessed an indomitable will and a perseverance rarely if ever equaled by any American collector; he had a keen eye and knew a good specimen at sight.

In the development and prosecution of this work his services to science were many and important. They were principally of two kinds: the discovery and procuring of material before unknown or inaccessible, and the distribution of good, well determined minerals throughout the cabinets of the whole country. The union of energy and accuracy in work of this character by Professor Foote has made his influence of great and permanent value.

Professor Thomas Egleston says of him:

> "He was certainly the most enterprising mineral collector and merchant that we have had in this country. No one ever did so much to disseminate a knowledge of American minerals in Europe as he."

Professor E. S. Dana writes:

> "My relations with the late Dr Foote extended over some twenty years and I thus had full opportunity to become acquainted with the unfailing activity and tireless enthusiasm which he dovoted to his mineralogical work. His explorations after minerals extended from Canada in the north to Mexico in the south, and to all parts of our western country. He also made several journeys to Europe, and collected zealously from England to Sicily and Austria. His work was carried on with the same energy even when his health was seriously impaired. The results of his labor are to be found in the development of American mineral localities and in the distribution of specimens not only throughout this country, but to many parts of the world, by which the knowledge of mineralogy and the general interest in its study have been much increased."

To illustrate briefly the points thus made by these eminent leaders in scientific mineralogy from whom I have just quoted, I may refer to three aspects of Professor Foote's work, namely, its extent, its accuracy, and its importance in respect to developing localities.

In the twenty-eight or thirty years of his collecting, he has placed in the cabinets of the world several millions of specimens, besides many thousands of small cabinets in which the specimens were sold as low as one hundred for a dollar. The impulse given and the facilities afforded both to beginners and to advanced collectors by this vast amount of distribution are beyond calculation in their influence on the development of this branch of study.

But with all this wide extent the work was accurate. On every specimen, even the little pieces in the beginner's collections, was pasted with a remarkably firm cement a label bearing the name of the species, the variety, the locality, the formula, and the number in Dana's Mineralogy. It is much to say, but I can say it without hesitation, that in all these vast numbers of specimens Professor Foote never allowed a single one to leave his establishment about which there was with him the slightest doubt as to the authenticity of the specimen or the correctness of the label.

As to localities, Professor Fŏote did an immense amount of pioneer work, both in opening and developing old localities and in discovering new ones. This alone entitles him to the gratitude of all lovers of the science. As early as 1870 he began this work in the region of lake Superior, accompanied by a class of students.

He spent some five months at Isle Royale and obtained many magnificent specimens of chlorastrolite, finer than any that had ever been found. He brought to light also the interesting gemstone to which he gave the name of zonochlorite, and which was generally recognized as a distinct species, although it has recently been referred to prehnite by Hawes.

At about the same time he visited the lead and zinc mines of Joplin and Oronogo, in southeastern Missouri, and was among the first to bring specimens from that region to the notice and within the reach of eastern collectors.

The same may be said of his work near Hot Springs, in Arkansas, whence before only a few stray specimens had been obtained of the beautiful quartz that has now become so abundant in cabinets, while the minerals of Magnet cove, the arkansite, wavellite, variscite and many others were almost or entirely unknown.

Somewhat later he developed on an extensive scale the great locality of amazonstone and smoky quartz at Pike's peak, and sent these elegant specimens far and wide to enrich the public and private collections of the whole world.

He discovered and brought to notice mazapilite, paramelaconite, cacoclasite and footeite, all of which were fully described by Dr George A. Koenig.

The magnificent twin zircons and apatites of Canada, the copper minerals from Arizona and New Mexico, the hanksite and other minerals from California, etcetera, are a few of the fine minerals he brought to light.

His monthly bulletins containing announcements of new mineral consignments, with valuable mineral notes, and republishing scientific papers and widely distributing them throughout the United States had much to do with bringing scientific information before the public. Another great work was his scientific book business; the bringing together of old libraries or scientific books that had found their way into the common old bookstores, cataloguing them and placing them at the disposal of active workers by means of monthly bulletins.

Professor Foote was always interested in expositions, and made excellent displays at the Centennial Exposition, 1876; Louisville, Kentucky; Cincinnati, Ohio; Paris, 1889, and at the Colonial Exposition of 1880, at which time he delivered a course of lectures on minerals and gems before the Workingmen's Association with considerable success.

Perhaps, however, his most important work, from a scientific standpoint, was in connection with the occurrence of diamonds, or at least of diamond-carbon, in meteorites. This was in 1891, when he visited the region of Canyon Diablo, Arizona, and brought thence several large meteorites and many small pieces of the iron meteorite that has since become so celebrated. The extreme hardness developed in portions of one of the masses in the process of cutting led to special investigation by Dr George A. Koenig, and the result was that small quantities of diamond-carbon were found in cavities in the iron. These facts were announced by Dr Foote at the Washington meeting of the American Association for the Advancement of Science in the same year, 1891. Two years later, at the World's Fair at Chicago, the powder from one of these cavities was successfully tested under my own direction by being used in actually polishing a diamond, and its character established beyond any possible doubt.

He has done a special work for mineralogy in this country which entitles his name to honor and regard. The great business that he has built up and administered is, we understand, to be carried on by his son, and, for the sake of science, we trust may be equally successful.

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In the absence of the author, the following memorial was read by the Secretary:

MEMOIR OF ANTONIO DEL CASTILLO

BY EZEQUIEL ORDOÑEZ

Señor Antonio del Castillo was born in 1820, of Mexican parents, in a little town called Pungarabato, state of Michoacan, in the Republic of Mexico. He was baptized in the town of Cutzamala, in the state of Guerrero, and was the fourth son of General Antonio del Castillo, a man of many battles, who held one of the first positions in the Mexican army, and was elected governor of the state of San Luis Potosi; his entire career was satisfactory to the Mexican people and he was worthy of mention in the biography of his son. The mother, Madam Marcelina Patiño, was of good family and seems to have possessed not only much love for her favorite son, but also much faculty of observation. She early discovered his fondness for certain studies and his appreciation of all things pertaining to nature. The parents sent the young Antonio to a school in Mexico kept by a Frenchman called Matyen de Fossey. He remained in this school from 1832 to 1835, whence he passed to the College of Mines. In this institution, supported and intended only for the sons of the wealthy and others holding high positions in Mexico, he was surrounded by people of wealth, birth and education. At the age of 26 years he was elected as substitute in the chair of mineralogy in the Mining College. One year later, when he graduated with high honor, the chair was made his permanently.

Some years afterward he married Miss Manuela Ocampo, the daughter of a rich merchant of Guadalajara. Here commences the public life of Señor Antonio del Castillo, who seems to have combined the love of family with love of science.

General Castillo in 1851 called his son to San Luis Potosi to take part in political affairs, but the professor preferred to continue his studies in geology.

In 1856 he made a trip to the United States, called there by the government to testify in court as to the ownership of certain mines in Almaden, California, claimed by two contesting parties. While there with other Mexican commissioners he received many flattering proofs of esteem and appreciation.

In 1866 he conceived the idea of making a geological map of the Republic of Mexico, notwithstanding his many occupations.

In 1867 the Mexican government appointed him Director of the Mint, and later one of the Commissioners to form a code of mining laws. When General Diaz became President, he appointed Señor Castillo Director of the School of Engineers. Having great affection for this school, he endeavored to increase in every way its usefulness, and under his directorship the government established many new classes and the school increased greatly in various departments.

During the French war, not being in sympathy with the Maximilian government, he left for a time his position in the school and took charge of the mines in Tasco, for which services he received valuable remuneration.

Señor Castillo was a man well known at home and abroad, as shown by his membership in the following scientific societies: Sociedad Mexicana de Geografia y Estadistica, Sociedad de Historia Natural, Asociacion de Yngenieros y Arquitectos, Societé Geologique de France, Societé de Economie Politique de Belgique, Geological Society of America, Geological Society of London, Deutsches Geolgisches Gesellschaft and American Institute of Mining Engineers.

In 1889, when representing the Mexican government in the Paris Exposition, he was made Chevalier of the Legion of Honor.

His chief work up to the year 1889 was in forming the Geological Commission of Mexico. This commission has made a sketch of the geological map of the Republic of Mexico, obtained knowledge of the mineral, volcanic and other products of different states and has transported to the capital the heaviest masses of meteoric iron to be found in the world.

Señor del Castillo was the Mexican representative in the Geological Congresses of London, Paris, Washington and Switzerland. His last wish when on his deathbed was to assist the Americanist Congress held in Mexico a few months since.

He died November 27, 1895, at 11 o'clock in the morning, in the city of Mexico. Two daughters survive him.

Notwithstanding his ability and experience as a practical geologist and mineralogist, Señor Castillo wrote but a few pamphlets on his favorite study.

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The presentation of scientific papers was declared in order, under the usual rule governing the position of papers in the program. The first and second papers were read by title.

DISINTEGRATION AND DECOMPOSITION OF DIABASE AT MEDFORD, MASSACHUSETTS

BY GEORGE P. MERRILL

The paper is printed as pages 349–362 of this volume.

GEOGRAPHIC RELATIONS OF THE GRANITES AND PORPHYRIES IN THE EASTERN PART OF THE OZARKS

BY CHARLES R. KEYES

The paper is printed as pages 363–376 of this volume.

The next paper was read by the author:

ILLUSTRATIONS OF THE DYNAMIC METAMORPHISM OF ANORTHOSITES AND RELATED ROCKS IN THE ADIRONDACKS

BY J. F. KEMP

[*Abstract*]

Essex county, New York, with about 2,500 square miles of area, contains the principal portion of the Adirondacks. As field-work has progressed year by year

the geological problems involved have become more clearly appreciated, and although the survey has necessarily up to this time been largely in the nature of reconnoissance, it has brought out much that is definite. Previous papers* before the Society have discussed several of these points. It is evident that with a series of gneisses which are in part thought to be of sedimentary origin on account of the crystalline limestones involved in them, there is also present a vast amount of intrusive or plutonic rocks of the gabbro family. They constitute the high peaks and ridges and include purely feldspathic aggregates or anorthosites and very basic olivine-gabbros with various intermediate types, all of whose genetic relations it is hoped in the future to demonstrate with chemical analyses and petrographic descriptions. The massive varieties are comparatively simple problems, but the widely prevalent gneissoid types, with the same mineralogy as the above massive forms, have proved extremely puzzling. Specimens have been gradually accumulated, however, and observations have been recorded, so that a practically unbroken series can be established from the massive to the gneissoid, together with the development of some secondary minerals of which garnet is commonest. The observations are of value not alone in their local application, but in illustrating in a remarkably clear way progressive dynamic metamorphism. With this object in view the writer placed in serial order about twenty-five specimens which he exhibited with comments.

First were shown perfectly massive and coarsely crystalline anorthosites from the vicinity of lake Sanford. They are dark blue or almost black aggregates of large labradorite crystals and practically nothing else. Next specimens were shown in which the rims of the labradorite crystals were crushed, first, with a narrow border of cataclastic fragments, then with broader and broader crushed rims, until the large crystals were only represented by irregular nuclei in a pulp of feldspar. The extreme case involved the comminuted fragments alone. These latter badly crushed varieties were called "pulp-anorthosites," and showed slight if any development of foliation or of shearing. A second series of specimens illustrated this phase, and the passage of the crushed anorthosites and acidic gabbros into augen-gneisses and finally into thinly foliated gneisses was traced step by step. The rich development of garnets in many was also shown. Starting again with massive olivine-gabbro possessing an almost ophitic texture from a great ledge north of Port Henry, the passage of this in the same outcrop through faintly gneissoid varieties into thinly laminated types was illustrated step by step, the final product being practically a hornblende schist.

All these changes were explained by crushing, flowage and shearing from dynamic processes attendant on the pre-Cambrian upheavals in the region. The least crushed or sheared varieties favor the central peaks or the interior parts of the larger ridges. The outer flanks are characteristically crushed or gneissoid. The confident hope was expressed that by establishing such series the origin of many of the obscure gneisses could be explained.

Acknowledgments were made to Professor James Hall, state geologist, under whose direction much of the material used in illustration had been gathered.

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* Gabbros on the western Shore of Lake Champlain. This Bulletin, vol. 5, p. 213.

Crystalline Limestones, Ophicalcites and associated Schists in the Eastern Adirondacks. Idem., vol. 6, p. 241. To these may be added Preliminary Report on the Geology of Essex county. Report of the New York State Geologist, 1893, p. 433. Geology of Moriah and Westport Townships. Bulletin State Museum, vol. iii, p. 325.

The paper by Professor Kemp was discussed by A. C. Lane and C. H. Hitchcock.

Following the presentation of the above paper the Society removed from room 104, which was found too small, to the geological lecture-room, on the same floor, where all the subsequent sessions of the meeting were held.

The next paper was read by the President, Vice-President Charles H. Hitchcock assuming the chair.

THE SHARE OF VOLCANIC DUST AND PUMICE IN MARINE DEPOSITS

BY N. S. SHALER

[*Abstract*]

It has long been recognized that those parts of the rock ejections of volcanoes which are, from their vesicular nature, in a condition to float in water, may be carried far over the seas and in time be contributed to the deposits which are forming on their floors. The object of this paper is to consider the probable amount of these contributions and the conditions of the distribution on the ocean bottoms and along the coast lines.

The distribution of volcanoes, so far as it is known, indicates that they are intimately related to actions going on beneath the sea floor. The facts justify us in believing that these vents plentifully develop on the ocean bottoms, but only in a limited way are formed along a strip of the continents next the shore, rarely if ever remaining in considerable activity after the sea has been withdrawn for more than two or three hundred miles from their sites. It is not certain that the submarine vents which are covered by any considerable depth of water discharge ashes or pumice. It is quite likely that the pressure of the overlying fluid prevents the free expansion of the interstitial steam, which, taking place in a limited way at the surface, forms pumice, or, occurring in a more effective manner, blows the lava to dust-like bits. It is, indeed, likely, though by no means certain, that, poured forth in the depths of the sea, the molten rock would be retained in a rather compact state or at most that the expansion of the gases would lead to the formation of somewhat vesicular lavas.

Limiting, as there seems reason to do, the formation of dust and pumice to the shore or shallow-water volcanoes, is there any means whereby we can obtain any measure, however rude, as to the amount of the ejections of the floatable material which they discharge? So far I have found but one region of extended and varied igneous activity where approximate estimates can be applied to the matter, that is the Javanese archipelago, including the island of the name, Sumatra and some of the neighboring lesser isles. It is a characteristic feature of the volcanoes of this district that the explosions are of great intensity, little flowing lava being extruded, the greater part of the molten rock being blown into pumice or dust. A study of the eruptions which have taken place in this field during the century and a quarter, ending in the great outburst of Krakatoa in 1883, makes it appear probable that the comminuted or extremely vesicular lava which has fallen upon the surface of the sea or in places on the land, whence it would be washed by the rain to the ocean, has amounted to somewhere near a cubic mile per annum. Although the Javanese archipelago appears to be, for its area, the place where the largest amount of vesicular or finely divided lava is now produced, we cannot, on the review of the facts, assume that more than from one-fifth to one-tenth of the contributions of those materials come from this limited field. Therefore, on the basis of this very rough reckoning, we may perhaps estimate the annual contribution to the seas of these rocks which may float in the water at somewhere near five cubic miles.

The Mississippi river each year discharges into the sea about one-twentieth of a cubic mile of suspended or dissolved mineral matter. It is doubtful if the aggregate discharge of the rivers of the world amounts to more than thirty times that of the Mississippi, so that the importation of sedimentary materials into the sea by the rain water may be in quantity much less than that contributed directly by the volcanoes. As yet the value of coastal erosion is not even approximately known, but assuming that the eastern coast of the United States affords a fair basis for such measurement, it seems likely that the volcanic ejections which fall upon the sea or are quickly washed into it equal, if they do not exceed, the coastal detritus.

The distribution of the vesicular fragmentary lava which may float upon the sea is evidently wider than that of the ordinary detritus from the land. In general, the range of the carriage of the fragments depends on the specific gravity of the bits. It is easily seen that there is a great diversity in this feature. As regards the dust, there is also a variation due to the size of the fragments. These may be so small that, as in the case of those formed during the eruption of Krakatoa, the rate of fall even through the air may be very slow. These diversities in the rate of descent probably result in the deposition of a great part of the dust and pumice on the sea-bottom at no great distance from the vent. A large portion of these materials evidently journey far and normally find their place of rest on the seashore in the well known manner of driftwood. As evidence of a certain though limited value as to the truth of this proposition the following facts may be noted:

Along the eastern and southern coasts of Florida the writer in 1887 noted the occurrence on the beach of numerous fragments of volcanic pumice. The quantity was so considerable that a number of observations showed that each square yard of the surface would on close inspection reveal a number of bits nearly all of which were evidently breaking up under the blows of the waves into unrecognizable powder. A further search of the Atlantic coast as far north as Eastport, Maine, has shown the presence of this material, though in lesser quantities. An extended correspondence has indicated like occurrences of pumice on the Pacific coast of the United States.

Although there is danger that inexperienced observers may mistake the pumaceous ash which is formed about the grate bars of the boiler fires of steamships or in other similar conditions, it is not difficult to discriminate the natural from the artificial product, at first by the included minerals and after the eye is well trained by the macroscopic aspect of the material.

Some of the bits of pumice which has recently come upon the Atlantic coast of the United States somewhat closely resembles that which was thrown out by Krakatoa in August, 1883. Without making too much of this likeness, it may be noted that there is no other more likely source of origin of these fragments.

The main points of this paper pertain to the question as to the amount of the material from volcanoes which may float in the sea (an amount which though not definitely measurable is evidently large) and to the natural fate of the fragments which are to be cast upon the sea beaches and from them come to the deposits which are forming in the littoral zone or to be dissolved in the sea water. The further consideration may be noted, namely, that in the region where volcanoes commit large amounts of finely divided lavas to the sea, with a consequent speedy formation of sediments, the result is likely to be a more than usually rapid upward movement of the isogeothermal planes in rocks containing a large proportion of water. This would naturally lead to explosions of exceeding violence, such as characterize the Javanese archipelago.

The paper by President Shaler was discussed by C. H. Hitchcock, C. W. Hayes, L. V. Pirsson, M. E. Wadsworth, Persifor Frazer, W. M. Davis and the author.

The following paper was read by the author:

A NEEDED TERM IN PETROGRAPHY

BY L. V. PIRSSON

[*Abstract*]

The term crystal when strictly and properly applied means the geometrical form assumed by the physical molecules of a definite chemical compound or by isomorphous compounds in crystallizing—that is, in arranging themselves according to certain laws of symmetry. Thus on hearing the term crystal we always imagine to ourselves this outward symmetrical form.

The demands of petrography have, however, often conferred upon the term another slightly different conception, in which greater stress is laid upon the internal molecular structure and physical properties of the body than upon its outward form. Thus we hear of "idiomorphic" crystals, though using the term in its strict sense every crystal must be idiomorphic.

This being the case, it seems clear that we have no good term to express those bodies which, though possessing the internal molecular structure and physical properties of crystals, have through the conditions of their growth not been able to attain outward symmetry.

Thus in augitic rocks we often find, on the one hand, cases where the pyroxene has crystallized freely as a phenocryst; it is idiomorphic, possesses its outward form bounded by crystal faces and is truly a crystal. On the other hand, we frequently find cases where the pyroxene has had its growth interfered with by that of other minerals and it has no definite geometrical form; it may often be found in granules or in rounded or ellipsoidal bodies.

While these latter forms are generally called crystals, referring especially to their internal structure, a survey of the literature will show that mineralogists, and especially petrographers, have felt the need of a more precise and definite term to denominate them. Thus we sometimes find them called "crystal fragments," a usage which is objectionable, since, if literally taken, it would mean that they were portions of a formerly larger mass of the same material, which they by no means are. Again, others have called them "crystalloids," but a difficulty in the use of this term lies in the fact that it has long had a perfectly definite and well defined meaning in chemistry of a totally different kind—that is, as the correlative of colloid. Petrographers can never hope to dispossess the chemists of their use of this term even if it were desirable to do so.

Feeling like others the need of a term to express the idea which has been mentioned above, the writer at the happy suggestion of Professor E. S. Dana, whom he has consulted upon the subject, offers the word *anhedron* (from α, privitive, and ʿεδρα, a plane, meaning "without planes"), and by anhedron then is meant those rounded or indeterminate forms without crystal planes in which minerals occur, especially in igneous rocks.

It will be noticed that the word is formed like a variety of well known terms, such as octahedron, which are used in crystallography to express outward form. Like them also it may be used in an adjectival manner, and we may speak of the pyroxene of a certain rock as occurring in anhedrons or as having an anhedral development.

The last paper of the session was read by the author.

NOTE ON THE OUTLINE OF CAPE COD

BY W. M. DAVIS

Remarks were made by G. K. Gilbert, C. H. Hitchcock and the President. This paper is published in the Proceedings of the American Academy of Arts and Sciences, 1896.

Announcements were made of a reception at the residence of Dr Horace Jayne and a lecture at the hall of the Academy of Natural Sciences by Professor William B. Scott, both being complimentary to the several visiting societies.

The Society then adjourned until Friday morning. No evening session was held.

Session of Friday, December 27

The Society convened in the geological lecture-room of the Department of Arts at 10 o'clock a m, President Shaler in the chair.

The Council's report was taken from the table and adopted without debate.

The Auditing Committee reported that they had examined the accounts and vouchers of the Treasurer and had found them correct and agreeing with the printed report. The report of the committee was adopted.

The following report of the Photograph Committee was read by J. F. Kemp:

SIXTH ANNUAL REPORT OF COMMITTEE ON PHOTOGRAPHS

To the Council of the Geological Society of America:

The Committee on Photographs have to report the addition of 188 views, bringing the full number now in the collection up to 1,283. The donors are F. V. Marsters (9), The Grabill Portrait Company of Chicago (13), E. L. Ferguson, Washington, D. C. (6); Samuel Calvin, Des Moines, Iowa (50); U. S. Geological Survey (H. W. Turner) (40); R. T. Hill, U. S. Geological Survey (51); W. H. Pynchon, Hartford, Connecticut (14); E. L. Edgerly, New York city (5).

The chairman wishes to state that, owing to the fact that copies of photographs are ordered directly from the donors, it is impossible for the committee to know just how far the collection meets the needs of the Society. They will therefore be very glad to receive suggestions from members with a view to increasing its efficiency. The size of the collection is already such as to make its care and transportation a matter of considerable expense, and it seems inadvisable to continue indiscriminately adding to its bulk.

If members will kindly indicate the character of views most needed the committee will be enabled to carry on its work more intelligently and satisfactorily.

Respectfully submitted.

GEORGE P. MERRILL,
Chairman.

WASHINGTON, D. C., *December 24, 1895.*

REGISTER OF PHOTOGRAPHS RECEIVED IN 1895

Nine views presented by F. V. Marsters

1095. Indiana oolitic stone quarry, Steinsville, Indiana.
1096. Sawed stone from Indiana Oolitic Stone Company, Steinsville, Indiana.
1097. Oolitic stone quarry (Saint Louis limestone), Herodsburgh, Indiana.
1098. Weathering of Indiana oolitic limestone, near Herodsburgh, Indiana.
1099. Sawed oolitic limestone, Bedford Stone Company, Bedford, Indiana.
1100. Hunter's quarry (Saint Louis limestone), Bloomington, Indiana.
1101. Reed's quarry, Clear creek, Monroe county, Indiana.
1102. Johnson's quarry, Bloomington, Indiana.
1103. End View. Largest block of stone (Indiana limestone) quarried up to September, 1893. Size, 11′ 9″ x 8′ 8″ x 10′ 4″; 1,054 cubic feet; weight, 190,000 pounds; quarried by Bedford Stone Company, Bedford, Indiana.

Thirteen views presented by the Grabill Portrait Company of Chicago, Illinois

1104. "White Rocks." Part of Deadwood, as seen from White rocks.
1105. "Gold Dust." Placer mining at Rockerville, Dakota. Old timers (Spriggs, Lamb and Dillon) at work.
1106. "Villa of Brule." The great hostile Indian camp on river Brule near Pine Ridge, South Dakota.
1107. "Deadwood, Dakota." A part of the city from Forest hill.
1108. "Echo Canyon." Looking through Sioux pass. On F. E. and M. Y. railroad, Hot Springs, South Dakota.
1109. "The celebrated Spearfish tin mine," Bear gulch, Lawrence county, South Dakota.
1110. "We have it Rich." Washing and panning gold, Rockerville, Dakota. Old timers (Spriggs, Lamb and Dillon) at work.
1111. "Spearfish Falls," Black hills, Dakota.
1112. "Giant Bluff," Elk canyon, on Black Hills and Fort Pierre railroad.
1113. "Signal Rock," Elk canyon, on Black Hills and Fort Pierre railroad.
1114. "Needle Point," Elk canyon, on Black Hills and Fort Pierre railroad.
1115. "Devils Tower." The Tower from the east side in mirage 1,200 feet high, 800 feet in diameter.
1116. "Devils Tower," showing millions of tons of fallen rock.

Six views photographed and presented by Eugene Lee Ferguson

1117. A part of Lamar, Barton county, Missouri. A typical Missouri prairie town. Photographed from court-house tower.
1118. A western Missouri coal mine.
1119. The Blue Ridge mountains in Virginia, showing western slopes and overlooking portion of Shenandoah valley. Sheep pasture in foreground.
1120. Perched rock in Westchester county, New York, near Mount Kisco.
1121. Perched rock in Westchester county, New York, near Mount Kisco.
1122. A rocky point on the Blue Ridge in Virginia, overlooking Shenandoah valley.

Fifty views presented by Samuel Calvin

Figures in parenthesis are original numbers

1123 (2). Riffle in Split Rock creek; caused by crossing a diabase ledge; Ristie's farm, near Carson, South Dakota. Photographed by Bain.
1124 (3). Cross-bedding in Sioux quartzite; Sioux falls, South Dakota. Photographed by Bain.
1125 (8). Canyon in Sioux quartzite; new; taken from bottom; Dell rapids, South Dakota. Photographed by Keyes.
1126 (10). Columns of Saint Croix sandstone; Lane's farm; Tp. 100 N., R. 4, Sec. 31, N. W. ¼ N. W. ¼. Photographed by Calvin.
1127 (13). The Elephant; Saint Croix covered by Oneota; over 300 feet high; on upper Iowa or Oneota river, near French Creek P. O., Allamakee county, Iowa. Photographed by Calvin.
1128 (14). Mount Hope; a hill of circumdenudation standing on a baseleveled plain; composed of Saint Croix overlain by Oneota; from south side of Oneota river; Tp. 100, R. 5, Sec. 34, N. E. ¼. Photographed by Calvin.

1129 (18). Bluffs on the upper Iowa or Oneota river, Saint Croix capped by Oneota; height 300 feet plus; near the mouth of Bear creek, Allamakee county, Iowa. Photographed by Calvin.

1130 (21). Oneota limestone; evenly bedded, fine quality stone; about 40 feet above Saint Croix; Tp. 100, R. 5, Sec. 18, N.W. ¼ S.W. ¼, N. E. cor. Photographed by Calvin.

1131 (*B*22). Part of the "Oyster shell rim" east of Fall river, showing peculiar concave topographic forms due to a bed of hard limestone charged with the shells of *Inoceramus* overlying softer beds; Benton group; northeast of Hot Springs, South Dakota.

1132 (25). Bluffs of Oneota limestone; on Yellow river below Ion; Tp. 96, R. 4, Sec. 24, N. E. ¼ S. E. ¼. Photographed by Calvin.

1133 (29). Bluff of Oneota limestone; massive above, cherty partings at base; height 60 feet; Tp. 96, R. 4, Sec. 16, S. W. ¼ N. E. ¼. Photographed by Calvin.

1134 (33). Cascade at Pinneys spring; in Trenton limestone, Allamakee county, Iowa. Photographed by Calvin.

1135 (31). Saint Peter sandstone, showing weathering effects; Tp. 96, R. 5, Sec. 14, S. W. ¼ N. W. ¼. Photographed by Calvin.

1136 (35). Upper Iowa or Oneota river, showing bluffs of Trenton limestone; Decorah, Iowa. Photographed by Calvin.

1137 (36). Effects of weathering on a bluff of Trenton limestone, illustrating thin bedding, etcetera; Tp. 96, R. 6, Sec. 17, S. E. ¼ S. E. ¼.

1138 (46). "Devils Den;" spring issuing from face of bluff of Trenton limestone; Tp. 99, R. 5, Sec. 19, N. W. ¼ N. E. ¼ N. E. cor. Photographed by Calvin.

1139 (55). Natural fall; Niagara limestone; Cascade, Dubuque county, Iowa. Photographed by Calvin.

1140 (56). Beds of passage between Niagara limestone and Maquoketa shale; Tp. 90, R. 4, Sec. 10; Delaware county, Iowa. Photographed by Calvin.

1141 (58). Niagara overlying Maquoketa, illustrating the effects of geologic structure on topographic form within the driftless area; the gently undulating lower slopes are underlain by the Maquoketa shale; the steep hills in the background are constructed of the overlying Niagara limestone; view looking south from Lattners, near Graf, Dubuque county, Iowa. Photographed by Calvin.

1142 (63). Steamboat rock; "Devils Backbone," topography of region similar to that of driftless area; northwestern part of Delaware county, Iowa. Photographed by Calvin.

1143 (64). Stairway at "Devils Backbone," illustrating effects of weathering on Niagara limestone; northwestern part of Delaware county, Iowa. Photographed by Calvin.

1144 (75). Cross-bedding in sandstone; Saint Louis; Bellefontaine, Makaska county, Iowa. Photographed by Bain.

1145 (79) Cross-bedding in Coal Measures sandstone; Redrock, Marion county. Photographed by Keyes.

1146 (80). Coal Measures sandstone and shale; foot of Capitol hill, Des Moines, Polk county, Iowa. Photographed by Bain.

1147 (83). Gypsum quarry face; Cretaceous; Iowa Plaster Company, Fort Dodge, Webster county. Photographed by Keyes.

1148 (87). Dakota formation, showing clays, lignite and sandstone, capped by loess; Sargeants bluff, Woodbury county, Iowa. Photographed by Bain.

1149 (88). Dakota and Benton formations; on the Sioux river, Old Crills mill, below Westfield, Plymouth county. Photographed by Bain.

1150 (89). Chalk cliff; Niobrara; on Sioux river, Old Crills mill, below Westfield, Plymouth county. Photographed by Bain.

1151 (94). A crowded field of foraminifera with medium sized *Textularia*, and many specimens of *Anomalina* magnified 55 diameters; from Saint Helene, Nebraska. Photographed by Calvin.

1152 (102). Flood plain of the Missouri; view taken from high bluffs east of the Sioux river; showing that river at the base; Dakota lowland between it and the Missouri, with the Nebraska hills south of the Missouri in the distance; Old Crills mill, below Westfield, Plymouth county, Iowa. Photographed by Bain.

1153 (106). Glacial scorings; Kingston, Des Moines county. Photographed by Fultz.

1154 (111). Till interbedded in loess; sand pits north of Sioux City, Woodbury county, Iowa. The hammer points to a boulder of Sioux quartzite. Photographed by Bain.

1155 (117). Base of Redrock bluff; east end of quarry; Redrock, Marion county, Iowa. Photographed by Keyes.

1156 (118). Quarry in upper Coal Measures; new workings; Earlham, Madison county, Iowa. Photographed by Bain.

1157 (124). Quarry in Devonian limestone; Cedar Valley stage; showing two parallel joints, near Iowa City, Johnson county, Iowa. Photographed by Calvin.

1158 (128). Iron mine, northeast of Waukon, Allamakee county, Tp. 99, R. 4, Sec. 36, N.W. ¼ S. E. ¼. Photographed by Calvin.

1159 (140). Palisades, showing Sioux quartzite on Split Rock creek, Minnehaha county, South Dakota. Photograph reduced by Calvin.

1160 (141). Palisades as in 140; distant view. Photograph reduced by Calvin.

1161 (142). Exposure of Le Claire limestone, obliquely bedded below, horizontally bedded above. Sugar Creek lime quarries, Cedar county, Iowa. Photographed by Houser.

1162 (143). View in Stone City quarry. Dearborne & Sons, proprietors. Anamosa stage of Niagara; Stone City, Jones county, Iowa. Photographed by Calvin.

1163 (144). View in Champion quarry, Stone City, Iowa; Anamosa stage of Niagara. Photographed by Calvin.

1164 (145). Oblique bedding in Le Claire limestone, half a mile south of Le Claire, Iowa. The soil at top of exposure is an ancient shell heap or kitchen-midden. Photographed by Calvin.

1165 (146). Exposure of thin bedded Le Claire limestone, Le Claire, Iowa, showing effect of subaquatic erosion and subsequent deposition of similar limestone in eroded trough. Le Claire, Iowa. Photographed by Calvin.

1166 (147). View in Cedar Valley quarry. E. J. C. Bealer, proprietor. Anamosa stage of Niagara limestone, Cedar Valley, Iowa. Photographed by Calvin.

1167 (148). Oneota river bluffs of dolomitized Devonian limestone. Foreston, Howard county, Iowa. Photographed by Calvin.

1168 (149). The Buchanan gravels, an interglacial, probably Aftonian deposit of water-laid, cross-bedded sands and gravels. The boulders in foreground have been thrown out of the gravel, and are of the Kansan drift type. The gravels are overlain by a thin layer of Iowan drift with numerous large granite boulders (see number 151). Photographed by Calvin.

1169 (150). Granitic boulders of Iowan drift near Winthrop, Iowa. Photographed by Calvin.

1170 (151). Boulders of Iowan drift overlying interglacial deposits, the Buchanan gravels, near Independence, Iowa. Photographed by Calvin.

1171 (152). Granite boulder of Iowan drift. Section 16, Newton township, Buchanan county, Iowa. Photographed by Calvin.

1172 (153). Boulders in Iowan drift. Buchanan county, Iowa. Photographed by Calvin.

Forty views presented by the U. S. Geological Survey (H. W. Turner).

1173. Laminated and roughly columnar fine grained pyroxene-andesite. Franklin Hill (Bidwall Bar atlas sheet), California. See Journal of Geology, volume iii, 1895, page 410. (Specimens, numbers 209, 661, etcetera.)

1174. Moraines two miles northeast of the Sierra buttes (Downieville atlas sheet). It will be noted that the longer moraine lies directly across an earlier moraine.

1175. Potholes in the granite of the canyon of the north fork of the Mokelumne river, California. See American Journal of Science, volume xliv, page 453.

1176. Canyon of the north folk of the Mokelumne river, near its head, southeast corner of the Pyramid Peak atlas sheet. This portion of the canyon is glaciated.

1177. Farewell gap, at the head of the drainage of a branch of the middle fork of the Kaweah river, Tulare county, California. In the southern Sierra Nevada. Elevation of the gap about 10,500 feet.

1178. The shattered granite crest of the Sierra Nevada, about six miles southeast of Tower peak, in Tuolumne county, California.

1179. Glaciated canyon north of lake Eleanor, Tuolumne county, California, showing the roches moutonnée. All the rock is granite.

1180. Granite bank west of Granite lake, Tuolumne county, California, showing basic nodules in the granite and dikes of aplitic granite (granulite of Levy) cutting both the main granite mass and the included nodules. See 14th Annual Report U. S. Geological Survey, page 480.

1181. View in Hetch-hetchy valley on the Tuolumne river, Tuolumne county, California. Yosemite atlas sheet. The rock composing the bluff is granite.

1182. Basic (black hornblende and some feldspar) inclusions in porphyrite (altered andesite) dike by the middle fork of the Feather river. Sierraville atlas sheet.

1183. Basaltic dikes in andesitic breccia on ridge south of Poker flat, Sierra county, California. Downieville atlas sheet.

1184. Old andesite (porphyritic) tuffs west of the Salmon lakes, Sierra county, California; showing joint structure. The tuffs are of Jura-Trias age.

1185. Columnar lava of Jura-Trias age, about four miles north of the Sierra buttes, Sierra county, California. Downieville atlas sheet. The easterly dip of the lava layer is approximately indicated by the upper surface of the columns.

1186. Hornblende-pyroxene-andesite breccia on the ridge top near Saddle Back mountain, Sierra county, California, showing the angular character of the fragmental lava.

1187. Abandoned hydraulic gold gravel mine at Scales, Sierra county, California. Downieville atlas sheet.

1188. Lower Sardine lake and the Sierra buttes (Downieville atlas sheet), showing the sharp line between the glaciated rocks of the buttes and the moraine material which begins where the line in red ink is drawn.

1189. Exfoliating granite; view on the crest of the Sierra Nevada about three miles south of Raymond peak, Markleeville atlas sheet. See 14th Annual Report U. S. Geological Survey, page 481.

1190. Wind ripples in the sand, near west entrance to Golden Gate park, San Francisco.

1191. Wind ripples in the sand, near north entrance to Golden Gate park, San Francisco.

1192. Cascades hydraulic gold gravel mine, showing the deposits of a Tertiary river, east slope of the Grizzly mountains, Plumas county, California. Downieville atlas sheet.

1193. Fault scarp and depressed block to the east of it, at the head of Dogwood creek, Plumas county, California. Bidwell Bar atlas sheet.

1194. Poker Flat, Sierra county, California (Downieville atlas sheet), surrounded by volcanic mountains, chiefly of fragmental andesite.

1195. Neocene shore gravels resting unconformably in a water-worn surface of the Ione sandstones, three miles southeasterly from Buena Vista, Amador county, California. Jackson atlas sheet.

1196. Glaciated canyon of the head of West Walker river, Mono county, California. Taken from the crest of the Sierra Nevada.

1197. Sawtooth peak from Mineral King, Tulare county, California. Elevation of Sawtooth about 13,000 feet.

1198. Wind ripples in sand, by north entrance to Golden Gate park, San Francisco.

1199. Ione formation capped by Pleistocene gravels; south bank of Mokelumne river, just east of the Comanche bridge, Calaveras county, California. Jackson atlas sheet.

1200. Porphyritic granite, near Granite lakes, Tuolumne county, California. The larger potash feldspars are two inches long.

1201. Glaciated granite, about six miles north of Hetch-hetchy valley looking north, Tuolumne county, California.

1202. Granite lake, Tuolumne county, California, showing the glaciated surfaces.

1203. Silver peak composed of andesitic tuffs and lavas 3,700 or more feet thick in thickness, Alpine county. Markleeville atlas sheet.

1204. Glaciated knob of columnar hornblende andesite, three miles west of Silver peak, Alpine county, California. Markleeville atlas sheet.

1205. Vertical fissures in granite, north of Charity valley, Alpine county, California. Markleeville atlas sheet.
1206. Moraines north of Pleasant valley, Alpine county, California. The valley lies immediately south 600 feet lower than the moraines seen in the middle of the picture. Markleeville atlas sheet.
1207. Serrated ridges of andesite breccia, Mount Raymond, Alpine county, California. Markleeville atlas sheet.
1208. West peak of Mount Raymond, Alpine county, California, from Indian valley. The peak is composed of hornblende pyroxene andesite breccia. Markleeville atlas sheet.
1209. The summit of the Sierra Nevada, near Tower peak, Tuolumne county, California.
1210. The crest of the Sierra Nevada, Tower peak.
1211. Summit of the Sierra Nevada, near Tower peak, Tuolumne county, California. View taken in July.
1212. From Charity valley, Alpine county, California; showing the fissures and glaciated granite, with lavas on the ridge tops; Hawkins peak (hornblende-andesite) in the distance. Markleeville atlas sheet.

Fifty-one views presented by Robert T. Hill.

Figures in parentheses are original numbers.

1213 (35). Costa Rica. Ira Zu volcano; the ascent; altitude, 9,000 feet. Oak scrub above limit of tropical forest.
1214 (36). Costa Rica. Ira Zu volcano; the ascent above timber line; altitude, 10,500 feet; vegetation, heath scrub.
1215 (37). Costa Rica. Ira Zu volcano; ascent; outer view of crater.
1216 (38). Costa Rica. Ira Zu volcano; outer view of crater, composed of rolling cinder.
1217 (39). Inward view of north end of crater, showing craterlets and rolling boulder material.
1218 (40). Costa Rica. Ira Zu volcano; inward view of outer crater, showing rolling boulders down cinder slope.
1219 (41). Costa Rica. Ira Zu volcano; ancient floor of large crater within crater, showing one stratum of black lava in great mass of cinder accumulation.
1220 (42). Costa Rica. Ira Zu volcano; old cliff of lava on south side; remnant of ancient eruptions; modern eruptions are principally cinder and water.
1221 (43). Costa Rica. Ira Zu volcano; craterlets within crater, below floor of old crater shown in number 41. Nineteen of these were counted by Mr Hill.
1222 (44). Costa Rica. Ira Zu volcano; craterlets within crater, below floor of old crater shown in number 41. Nineteen of these were counted by Mr Hill.
1223 (45). Costa Rica. Ira Zu volcano; craterlets within crater, below floor of old crater shown in number 41. Nineteen of these were counted by Mr Hill.
1224 (46). Detail of slope of old crater floor shown in number 41.

1225 (47). Costa Rica. Ira Zu volcano; a wave of clouds slowly rolls over the crater suspending photographic operations.

1226 (48). View of Panama bay, showing islands of Naos in distance; modern erosion on right and littoral debris in foreground.

1227 (49). Hicaron island, in Pacific ocean, showing topographic features and modern erosion described by Mr Hill in paper on Panama.

1228 (50). Colon. Front, Panama railway buildings, showing church. Colonel Richard Wintersmith and United States Consul Pearcy in foreground.

1229 (51). Colon. Front, Panama railway buildings, showing monument erected to Aspinwall and Stevens, the chief promoters of the Panama Railway Company.

1230 (1). "Buccaneering." Old Panama, settled in 1518 by the Spaniards; destroyed by English buccaneers under Morgan in 1671. This tower alone remains to mark the site of the great city of the first century of Spanish conquest.

1231 (2). Panama. "Cerro Ancon," 600 feet high. Part of the hospital building of the Panama Canal Company in foreground.

1232 (3). Panama. "Anton's Folly." The palatial residence built by a former assistant superintendent of the canal company. His wife and two children having died in this building of indigenous diseases, he shot his coach horses and returned to France.

1233 (4). Panama. Interior of ruins of old cathedral, said to be over 100 years old. In the back of the pictuce will be seen a brick arch of about 30 feet span and less than 4 feet spring. The preservation of this arch testifies to the freedom of this region from serious earthquake disturbances.

1234 (5). Panama bay. The island of Taboga, famous for exquisite pineapples; the high bench on the left-hand side of the picture is a poor illustration of a persistent topographic feature of the Pacific coast.

1235 (6). Panama bay. The island of Naos; terminus of the Pacific Mail line, showing shops and buildings.

1236 (7). Colon. Residence of the superintendent of the Panama Railway Company at entrance of Limon bay.

1237 (8). Colon. Residence of "El Poblacion," showing Jamaica negroes and ready made farm-houses with corrugated-iron roofs; a public carriage is also seen.

1238 (9). Colon. Driveway of Cristofer Colon; the Panama canal suburb. The ground is made from debris of the canal dumped into the bay.

1239 (10). Colon. A dredge of the Panama Canal Company.

1240 (11). Panama canal, showing a portion of the 15 kilometers lying between Colon and Bujio, situated near the hills in background. The dredging has been continued to completion since this picture was taken.

1241 (12). Isthmus of Panama. A social gathering at Frijoles. The ladies have their weekly washing bees, during which the current news is disseminated. With two exceptions these women are Jamaica negresses, the chief laborers of the tropics.

1242 (13). Canal cutting through massive basaltic rock near San Pabloa.

1243 (14). Canal cutting through massive igneous rock near Paraiso.

1244 (15). Dredges in the Panama canal.

1245 (16). Scene on the Rio Chagres.

1246 (17). Costa Rica. Swamp lands of the Atlantic coast, showing typical vegetation of that region and the isthmus. Aborigines in the foreground.

1247 (18). Coastal portion of Revancon. Atlantic drainage of Costa Rica, showing igneous debris brought down by streams.

1248 (19). Aboriginal houses of Talamanca Indians, a powerful tribe inhabiting the southeast coast of Costa Rica.

1249 (20). Aboriginal houses of Talamanca Indians, a powerful tribe inhabiting the southeast coast of Costa Rica.

1250 (21). Aboriginal houses of Talamanca Indians, a powerful tribe inhabiting the southeast coast of Costa Rica.

1251 (22). Costa Rica. Upland scenery of central basin region; igneous boulder in foreground.

1252 (23). Costa Rica. Upland scenery of central basin region.

1253 (24). Costa Rica. Upland scenery of central basin region; road through Aguacate pass.

1254 (25). Volcanic boulder drift, the chief geologic feature of Central America.

1255 (26). The true tropical flora growing at altitudes between 2,000 and 5,000 feet, showing the wonderful parasitic growth upon the trees.

1256 (27). The true tropical flora growing at altitudes between 2,000 and 5,000 feet, showing the wonderful parasitic growth upon the trees.

1257 (28). The true tropical flora growing at altitudes between 2,000 and 5,000 feet, showing the wonderful growth of parasitic ferns upon the trees.

1258 (29). Costa Rica. Costa Rican soldiery. This peaceful country requires every citizen to serve a short period in the army. The paraphernalia of war so conspicuous in other Spanish American countries is unknown. Costa Rica is unique among American countries from the fact that it has never had a war.

1259 (30). Old cathedral, showing ancient Spanish architecture, still current in Mexico, but now replaced in Costa Rica by a more modern style shown in number (31) 1260.

1260 (31). Cathedral, San José, Costa Rica.

1261 (32). Costa Rica. Crater lake of Poas volcano.

1262 (33). Costa Rica. Crater lake of Poas volcano; geyser in operation.

1263 (34). Costa Rica. Outer rim of Ira Zu volcano; altitude, 11,400 feet.

Fourteen views presented by W. H. Pynchon, Hartford, Connecticut

1264 (1). Contact of Triassic conglomerate on underlying crystalline rock (schist). The locality is on Roaring brook, about 2½ miles west of Southington, Connecticut, and is on the line of the western boundary of the Triassic area of Connecticut. The upright slabs of rock in deep shadow and the rocks over which the brook flows are schist. The massive one hanging brow is Triassic conglomerate.

1265 (2). Detail of same locality as shown in (1) 1264.

1266 (3). Fault at Tariffville, Connecticut. Farmington river.

1267 (4). Cat-hole pass, near Meriden, Connecticut, showing the deep gorges formed on the line of the oblique northeast-southwest fault running between Notch mountain (South mountain) on the west and Cat-hole peaks on the east. The view looks to the southwest.

1268 (5). City stone pit, Hartford, Connecticut, showing contact of trap sheet (probably the "posterior") on the underlying shales. The roofs of Trinity College are seen above the ridge. The view looks a little east of north.
1269 (6). Slab of Triassic sandstone, showing mud cracks; size about 10 feet by 5 feet; Shaler and Hall quarry, Portland, Connecticut.
1270 (7). Section of the bed of volcanic ashes west of the southern end of Lamentation mountain, near Meriden, Connecticut. (See "The lost Volcanoes of Connecticut." W. M. Davis. Popular Science Monthly, 1891.) The picture, looking a little north of east, shows the flattened "bombs" imbedded in the ashes.
1271 (8). Detail of a part of same ash-bed, showing bombs imbedded in the ashes.
1272 (9). Contact of Calciferous on fundamental gneiss; Little falls of the Mohawk, New York. The locality is on a cut of the West Shore railroad. Close upon the gneiss is a thin layer of conglomerate, considered by Professor W. M. Davis to belong to Calciferous times and not to Potsdam times, as some have suggested.
1273 (10). Same contact, showing the thin (3 or 4 inches) layer of conglomerate.
1274 (11). Old shoreline of lake Ontario, near Rose village, New York, about three miles south of Sodus bay.
1275 (12). High falls of Genesee river at Rochester, New York. The lower fall (in the foreground) is determined by the Medina sandstone, the one next above by the Pentamerus limestone of the Clinton.
1276 (13). The Niagara escarpment, looking west. Between the camera and General Brocks' monument flows the Niagara river. Between General Brocks' monument and the distant headland of the escarpment is probably the broad mouth of the old drift-choked valley mentioned by Gilbert in his article on the history of Niagara (see Report of New York State Reservation).
1277 (14). The Niagara escarpment from inside the gorge, looking toward Queenston.

Five views presented by E. L. Edgerly

1278 (1). Glaciated surface, Bronx park, New York city.
1279 (2). Drift boulder, Bronx park, New York city.
1280 (3). Drift boulder, Bronx park, New York city.
1281 (4). Drift boulder, Bronx park, New York city.
1282 (5). Drift boulder, Bronx park, New York city.

It was voted that the report of the Photograph Committee be adopted. It was also voted that the committee be allowed an appropriation of $15 for 1896.

The Secretary announced that the Council suggested for the next summer meeting, to be held at Buffalo, a variation from the usual program. Instead of the several sessions for reading of papers it was proposed to organize a number of excursions previous to the meeting for the study of the different classes of geologic phenomena in the district surrounding Buffalo; to convene the Society for one session for administrative business and the reading of papers by title, and to permit the presentation of these papers subsequently in Section E of the American Association for the Advancement of Science.

The plan was briefly discussed with seeming approval as an experiment.

The first paper of the program for the day was the Presidential Address. Vice-President C. H. Hitchcock assumed the chair and the President read his address:

RELATIONS OF GEOLOGIC SCIENCE TO EDUCATION

BY THE PRESIDENT, N. S. SHALER

The President invited discussion, and remarks were made by G. K. Gilbert, H. S. Williams and M. E. Wadsworth, with replies by the author. The address is printed as pages 315-326 of this volume.

The President resumed the chair and the first paper was the following:

PLAINS OF MARINE AND SUBAERIAL DENUDATION

BY W. M. DAVIS

The paper was discussed by Bailey Willis, H. F. Reid, C. W. Hayes, C. R. Van Hise and G. K. Gilbert. It is published as pages 377–398 of this volume.

A communication was read from Dr George H. Horn, Secretary of the American Philosophical Society, inviting the Fellows to visit the rooms and library of that society.

An invitation was also extended to the Fellows, by the University of Pennsylvania, to partake of a midday luncheon served in the library.

Announcement was made by the Secretary that immediately after the noon adjournment the Fellows present would be photographed in a group.

The last paper of the morning session was read, entitled:

CUSPATE FORELANDS

BY F. P. GULLIVER

Remarks were made by Bailey Willis. This paper is published as pages 399–422 of this volume.

Adjournment was then taken for luncheon.

PORTION OF THE KAATERS KILL ATLAS SHEET, U. S. GEOLOGICAL SURVEY

SHOWING RELATIONS OF THE KAATERS KILL AND PLAATERS KILL AS STREAM-ROBBERS

A = Palenville; *B* = Mountain House; *C* = Kaaterskill House; *D* = Kaaters kill falls; *E* = Haines falls; *F* = Tannersville; *G* = West Saugerties; *H* = Sleepy Hollow; *J* = North mountain

Topography by J. C. Jennings

The Society reconvened at 2 o'clock p m and listened to the first paper as follows:

DRAINAGE MODIFICATIONS AND THEIR INTERPRETATION

BY M. R. CAMPBELL

The paper was discussed by W. M. Davis, G. K. Gilbert and the President. It is to be published later in the Journal of Geology.

The next paper was entitled:

EXAMPLES OF STREAM-ROBBING IN THE CATSKILL MOUNTAINS

BY N. H. DARTON

[*Abstract*]

When we investigate the history of development of drainage systems we often find instances in which a stream has cut through a divide and tapped the headwaters of a neighboring stream, a phenomenon known as stream-robbing. It is accomplished only when there are more favorable conditions of erosion along the stream which does the robbing, usually due to rock texture or attitude, but sometimes glacial influences, orographic displacements and chemical erosion are important factors.

Some of the best marked examples of relatively recent stream-robbing which I have seen are along the eastern face of the Catskill mountains. The two finest of these are the Plaaters kill and Kaaters kill, which have cut back several miles into the mountain and tapped the upper waters of two head branches of Schoharie creek. In plate 23 I have reproduced a portion of the Kaaters kill topographic sheet of the U. S. Geological Survey, which portrays these stream-robbers so plainly that an extended description of them will not be necessary.

The most conspicuous features of the region are the steep eastern front of the Catskill mountains and the deeply indented gorges of the Kaaters kill and Plaaters kill, all having very precipitous slopes, which are mainly over 1,500 feet in height. The gorges head in high waterfalls and they receive lateral branches, which also descend in falls of greater or less magnitude, of which the Kaaters kill falls are the most noteworthy. Lying above the heads of the gorges, there is an elevated upland containing the wide, gently sloping valleys of the headwaters of Schoharie creek. The divides at the heads of both the Kaaters kill and Plaaters kill gorges have an altitude of very nearly 1,925 feet above sealevel, and they are in saddles which are depressed about 1,600 feet below the summits of adjoining ridges. The former continuity of each branch of the Schoharie *depression* eastward beyond the present divide at the head of the gorges, is clearly apparent on the map (plate 23), particularly in the case of the north branch. From *D* to *E* a portion of the south side of this depression has been cut away bodily by the invasion of the Kaaters kill gorge, and the waters of the two lakes now pass over Kaaters kill falls at *D*, while a side branch from the northward passes over Haines falls at *E*. Some side branches of former Schoharie drainage from the southward now flow down gorges into the Kaaters kill opposite the Kaaters kill falls. The Plaaters kill similarly taps sepa-

rately three of the former head streams of the south branch of Schoharie creek, but its gorge has not so deeply invaded the original depression.

The geologic structure of the region is such as to facilitate stream-robbing by streams cutting backward in the face of the mountain. The formations are alternating beds of hard sandstone and soft red shales, which dip gently westward. A stream flowing on a hard bed down the dip would erode very slowly, and this has been the case with the branches of the Schoharie. They rise in an elevated portion of the mountain and after the first mile or two flow slowly to the westward and empty into the Mohawk river many miles to the northwestward. With streams flowing out of the mountain to the eastward the conditions are very different. Tidewater is only a few miles away, which gives great declivity, and on the steep mountain slope streams cutting back against the dip rapidly remove the red shales and undermine the sandstones. The relations of these features are shown in the following figure:

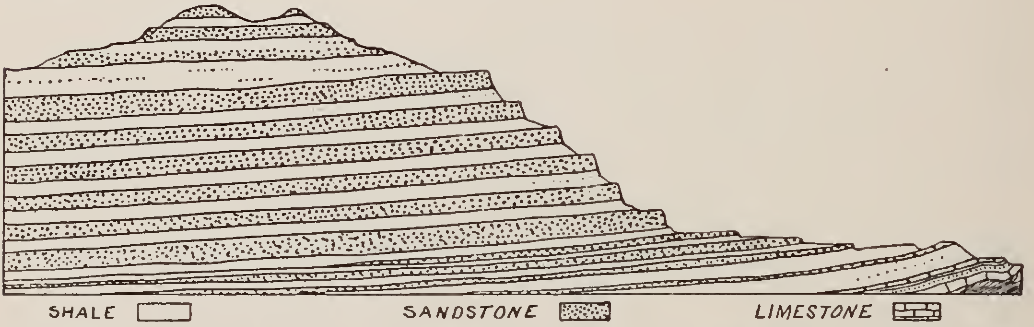

Figure 1.—*Cross-section of Front of northern Portion of Catskill Mountains near Kaaters Kill Gorge.*

The rapidity of erosion which progresses under these conditions is strikingly illustrated in the Kaaters kill and Plaaters kill gorges, where relatively small streams are causing the rapid recession of falls and deepening of the valley. Great chambers are rapidly excavated in the red shale beds, and although their roofs are usually of heavy beds of hard, cross-bedded sandstone, these soon fall as the undermining advances. The Kaaters kill falls, Haines falls and falls of the Plaaters kill are high, picturesque falls, which exhibit great thicknesses of the alternating hard and soft beds. The newness of the great gorges is very evident, and it is a feature strikingly in contrast with the wide, elevated depressions of the Schoharie branches which the enterprising Kaaters kill and Plaaters kill have invaded.

It was at no distant date, geologically, when the two lakes west of the Mountain House drained into the north branch of Schoharie creek along a depression which passed with gentle slope along by *D* and *E* (see plate 23) and merged into the present Schoharie depression at the present divide, three-quarters of a mile west of Haines falls.

The history of the Plaaters kill invasion was quite similar and is, I think, clearly indicated on the map. No doubt originally there were high gaps in the Catskill front where the Kaaters kill and Plaaters kill gorges now lie, which gave the invaders advantage over the other streams which head against higher portions of the front. These wind gaps occur frequently throughout the Catskills and are related to an earlier phase in the topographic development of the mountains, which I will not discuss here. There is strong suggestion of the former presence of a gap of this character in the gentle slope extending down from the Kaaterskill House for 225 feet to the edge of the very steep slopes of the Kaaters kill gorge. A study of the map will, I think, furnish various further evidences to the same end along both gorges.

Glacial influences may have been factors in the development of the gorges, but I do not believe they were important ones. I have ascertained that during the retreat of the glacial ice the Schoharie drainage was ponded by successive ice-dams before the ice had retreated beyond the confluence of the Schoharie and the Mohawk rivers. This gave rise to long, narrow lakes in the Schoharie valley, which at one time outletted into the Delaware river at Grand gorge, a narrow, low divide, at an altitude of 1,574 feet. Possibly at some stage of the ice-retreat the upper Schoharie waters were dammed so high that they flowed out through the wind gaps in the east front of the mountain and gave impetus to the development of the Kaaters kill and Plaaters kill gorges, but this overflow would probably have been very transitory and not of important influence.

I did not notice any stratified drift in the depression above Tannersville, but the valley contains more or less till up to and across the divide. The drift-filling appears to slope to the westward.

Mr Darton's paper was discussed by W. M. Davis and the President.

The following paper was then read :

MOVEMENTS OF ROCKS UNDER DEFORMATION

BY C. R. VAN HISE

This paper was discussed by several Fellows: A. C. Lane, H. F. Reid, J. F. Kemp, B. K. Emerson, J. P. Iddings and Bailey Willis. The paper is published in the Fourteenth Annual Report of the Director of the U. S. Geological Survey, pages 589–603.

The next paper was entitled :

PROOFS OF THE RISING OF THE LAND AROUND HUDSON BAY

BY ROBERT BELL

The paper was discussed by G. K. Gilbert, the President and the author.

The title of the next paper was :

POSSIBLE DEPTH OF MINING AND BORING

BY ALFRED C. LANE

Remarks were made by C. R. Van Hise and the President. The paper will be published in Mineral Industries, issued by the Engineering and Mining Journal.

The last paper of the session was entitled:

NOTES ON GLACIERS

BY HARRY FIELDING REID

[*Abstract*]

1. The request made last year for observations on the advance or retreat of American glaciers has brought but few responses; these, however, show that the Carbon river and North Puyallup glaciers on mount Rainier and the Illecellewaet glacier in the Selkirk mountains are retreating.

2. If we consider a glacier in equilibrium, the amount of ice flowing through any section in a year must equal the ice added to the glacier above that section in the same time. This, in connection with the fact that there is actual accumulation in the reservoir and melting in the dissipator (the region below the *néré* line), shows that the flow must be greatest in the neighborhood of the *néré* line and must diminish as we ascend or descend the glacier from that region. This law of flow is exact and must replace the similar empirical rule of velocity first stated by Désor. It is inferred that the greatest flow in the ice-sheet of the Glacial period must have been near the *néré* line, and that this was much nearer to the outer edge of the sheet than to the center of distribution. In general, the velocity will be greatest where the flow is greatest.

3. A consideration of the flow in a glacier of indefinite length resting on a bed of uniform slope leads to the conclusion that with ordinary glaciers the parts near the end must owe some of their motion to pressure from behind. This has been generally believed, but not clearly reasoned out.

4. As a result of this pressure there must be in the dissipator a motion of the ice away from the bed. In the reservoir, on the contrary, there is a motion toward the bed. We are enabled to draw approximately the lines of flow followed by the ice from the time of its deposition as snow to the time of its melting, and also to show the positions occupied by the successive strata.

5. If we knew the distribution of velocity and of melting we could calculate the form of the glacier's surface. The vertical or overhanging ends of some Greenland glaciers described by Professor Chamberlin during the past year are due to the large quantity of debris in their lower layers, causing more rapid melting there.

6. Glaciers are rarely in complete equilibrium with their surroundings. The relations establishing the form of the surface bring about a state of *unstable* equilibrium, and this would lead us to expect the great fluctuations in the extent of glaciers which we actually observe.

The paper was discussed by G. F. Wright, R. D. Salisbury, W. N. Rice and the President. The paper will be published in full in the Journal of Geology.

The Society then adjourned. No evening session was held.

Session of Saturday, December 28, 1895

The Society was called to order by the President at 10 o'clock a m.

The following resolution was unanimously adopted:

"*Resolved*, That the Geological Society of America sends its hearty greetings to our honored Fellow, J. P. Lesley, the veteran geologist of Pennsylvania, whose vast labors have furnished the people with a clear and comprehensive knowledge of the geological structure of this great State. We regret that enfeebled health prevents him from meeting with us, and we send him our cordial sympathy and best wishes and respects."

The reading of papers was declared in order, and the first paper was the following:

THE RELATION BETWEEN ICE-LOBES SOUTH FROM THE WISCONSIN DRIFTLESS AREA

BY FRANK LEVERETT

The paper was discussed by R. D. Salisbury, G. F. Wright and the President. The substance of this paper and the one following will be published as a bulletin of the U. S. Geological Survey under the title: The Illinois glacial lobe.

A proposition to divide the Society into two sections for the remainder of the program was not carried.

The second paper was by the same author as the preceding:

THE LOESS OF WESTERN ILLINOIS AND SOUTHEASTERN IOWA

BY FRANK LEVERETT

Remarks were made by G. K. Gilbert, B. K. Emerson, R. D. Salisbury and the President.

The third paper was entitled:

HIGH-LEVEL TERRACES OF THE MIDDLE OHIO AND ITS TRIBUTARIES

BY E. FREDERICK WRIGHT

The discussion was participated in by I. C. White, Frank Leverett, the President, Angelo Heilprin and G. K. Gilbert. A summary of this paper is published in the American Geologist, February, volume xvii, 1896, pages 103, 104.

The fourth paper was read by the Secretary:

FOUR GREAT KAME AREAS OF WESTERN NEW YORK

BY H. L. FAIRCHILD

The paper is published in the Journal of Geology, volume iv, February–March, 1896, pages 129–159.

The next paper was read by title:

PREGLACIAL AND POSTGLACIAL VALLEYS OF THE CUYAHOGA AND ROCKY RIVERS

BY WARREN UPHAM

The paper is printed as pages 327–348 of this volume.

The following paper was then read:

PALEOZOIC TERRANES IN THE CONNECTICUT VALLEY

BY C. H. HITCHCOCK

[*Abstract*]

Contents

INTRODUCTION

Since the termination of the geological survey of New Hampshire in 1878 the author has incidentally investigated the structure of the Connecticut Valley terranes and desires to place on record a few important conclusions.

REVISION OF THE ARRANGEMENT OF THE ARGILLITES

It is believed that one band underlies and the other overlies the calciferous mica-schist. The lowest one has not been traced farther south than Barnard and Hartland, Vermont, localities which represent two outcrops of the same terrane, twenty-five miles or more apart, but dipping toward each other. The more western range carries the Northfield quarries, and with an interruption in the La Moille valley passes into Canada along lake Memphremagog. Quarries have been wrought in the eastern band at North Thetford and Kirby, Vermont. Both ranges rest upon hydromica-schist and underlie the calciferous mica-schist.

The newer terrane embraces the rest of the "Cambrian slate" of my report, together with the staurolitic and garnetiferous slates called Coös. The two were separated in obedience to the principle that similar rocks belonged to the same age, while dissimilar rocks belonged to different ages. It now seems probable that an argillite may under certain conditions develop staurolite, andalusite, garnet and other minerals. This newer argillite enters Vermont from Massachusetts in Guilford and Vernon, and may be traced northerly to the southern part of Coös county, New Hampshire, and perhaps farther. The most important feature of delineation is the connection of the Guilford slate with a part of the Coös group in Charlestown, New Hampshire, which in turn joins a band of slate reaching to the north line of the southwest sheet of the general map, passing through Claremont. I find it is continuous still farther, at the expense of the Coös group, through Cornish, Hanover and Lyme, New Hampshire. It is probable that the synclinal area of slate in Bath and Lyman, New Hampshire, retains the same structure into Littleton and Dalton, constituting the principal portion of the Blueberry mountain range. None of this carries staurolite, but the segment carrying this mineral very prominently lies upon the east side of the Lower Ammonoosuc river in Lisbon, and is entirely separated from the former. For the tracing out of the slates in Charlestown I am indebted to Mr. G. D. Hull.

HORNBLENDE-SCHIST

In the neighborhood of Hanover this rock occurs in igneous bunches, varying in size from a peck-measure to a mass ten miles long. Planes of foliation traverse these masses with a quite constant inclination of fifty degrees northwesterly. On the northwest side of the principal range the schist comes successively in contact with mica-schist, hydromica-schist, argillite and chlorite-schist, all of which have been altered through heat into vitrified and indurated rocks, usually richer in silica than when unaltered. On the southeast side the adjacent rock is invariably mica-schist somewhat indurated. It is supposed the foliation is induced by pressure exerted at right angles to the dipping planes, but as there is no apparent material above the hornblende to act as a weight, it is conceivable that a great mass of mica-schist once occupied the place and has since been removed by erosion. In the smaller bunches both walls are present and their agency is apparent; hence the present attitude of the igneous hornblende is like that of the modern laccolite where the cap has been worn away.

PROTOGENE

The areas of protogene gneiss prove to be eruptive because they contain abundant inclusions of mica-schist, the inclosing rock. They are the Hanover-Lebanon and the North Lisbon end of the areas, colored *Bethlehem gneiss* upon the map. They were called Archean in the report with the approval of Professor J. D. Dana for the one and of Dr T. Sterry Hunt for the other. The foliated planes are obscure.

PALEONTOLOGY

The removal to the igneous category of the foliated hornblende-schists, diorites, diabases and two kinds of protogene, most of which had been classed with the Huronian, will simplify the determination of the age and relations of the schists associated with the fossiliferous terranes in Lisbon and Littleton. Niagara fossils, such as *Halysites, Pentamerus nysius and Dalmania limulurus,* occur there upon sediments partially converted into schists. The Swift Water series of the report will probably be found intimately connected with the fossiliferous bands.

CORRELATION

It is worthy of note that the Canadian geologists now refer the extension of the calciferous mica-schist to the Cambro-Silurian because of the presence of Trenton graptolites as determined by Lapworth. The earlier determination of Niagara was based upon outlying patches, which are now supposed to rest upon the older rock and not incorporated with it. The terranes referred to the Green Mountain gneiss and Huronian in my report become pre-Cambrian, and Cambrian as they pass into Canada.*

Remarks were made by B. K. Emerson.

The next paper was entitled:

THE DEVONIAN FORMATIONS OF THE SOUTHERN APPALACHIANS

BY C. WILLARD HAYES

Remarks were offered by D. W. Langdon, Jr., J. J. Stevenson, Arthur Keith, C. R. Van Hise and H. S. Williams. The paper will be published in the Journal of Geology during the coming summer.

The next two papers were read by the author, with no intermission.

NOTES ON RELATIONS OF LOWER MEMBERS OF THE COASTAL PLAIN SERIES IN SOUTH CAROLINA

BY N. H. DARTON

Contents

INTRODUCTION

Our principal knowledge of the geology of South Carolina is derived from studies made by Professor Tuomey a half century ago.† Tuomey's investigations covered the greater portion of the Coastal Plain area of the state before the geological survey was discontinued, and while the relations of many of the formations were

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* Bull. Geol. Soc. Amer., vol. 1, p. 453.

† Report on the Geology of the State of South Carolina, 1846.

determined, several very important features were not ascertained. These relate mainly to the lower members which lie on the east-dipping floor of crystalline rocks.

Statement of former and present Views

During the past two years I have given considerable attention to the question of artesian water supply on the Atlantic slope, and last winter found it necessary to visit eastern South Carolina for a brief study of the conditions in that region. As the lower formations of the Coastal Plain series promised to be important water-bearers I paid special attention to their characteristics and relations. From the descriptions by Tuomey it would appear that the Eocene formation includes in its lower portion a series of clays and sands which lie directly on the granite in the southern portion of the state, while to the northward the Cretaceous marls emerge from beneath the edge of medial Eocene beds. The formations underlying the Cretaceous marls were not fully described, and apparently they were also supposed to pass under the overlapping series of sands and clays of the lower Eocene, which is stated to lie directly on the granite in all the region south of the Wateree river.

From a study of this problem in the field I find that the so-called basal members of the Eocene are not Eocene at all, but are representatives of the Potomac formation, and this formation extends northward beneath the marine Cretaceous marls, of which the edge emerges from under the Eocene north of the Wateree river. Thus it was found, as suggested several years ago by McGee, that there is a continuous sheet of Potomac formation lying on the crystalline rocks throughout South Carolina. To the southward it is overlain by the Eocene formation and to the northward by a gradually increasing thickness of the marine Cretaceous marls, which also thicken to the southeastward out under the Coastal Plain, as shown by their great mass in the wells at Charleston.

Coastal Plain Sections in South Carolina

In the three sections comprised in figure 2 (page 514), I have attempted to present the matter as clearly as possible and to bring together all available data on the structure of the Coastal Plain portion of South Carolina.

The new information in these sections is derived from a study of the outcrop belt of the Potomac formation and from records and samples of artesian well borings. As there is now considerable prospect that wells will soon be bored in many places in eastern South Carolina, it is probable that at no distant time data will be obtained which will fully illustrate the underground structure of the region.

The Formations and their Characteristics

The principal formations of the Coastal Plain series in South Carolina are as follows:

Formations.	*Characteristics.*
Columbia.	Gray sands, etcetera.
Lafayette.	Orange loams.
Miocene.	Sands and marls.
Eocene.	Buhrstone below, marls above.
Marine Cretaceous.	Marls, sands and clays.
Potomac.	Sands, sandstones and clays.

Potomac Formation

Professor Tuomey described in considerable detail many of the more prominent outcrops of this formation in the southern portion of the state, but, as explained above, regarded it as the lower member of the Eocene. It outcrops in a belt four or five miles in width which extends from Augusta, Georgia; through Aiken; south of Lexington; through Columbia, and, I find, continuously into North Carolina via Camden and Cheraw. The basal beds are mainly coarse sands, with pebbles, which to the southward are sometimes consolidated to a soft sandrock. Finer sands and clays occur higher up in the formation, and it is these that are usually

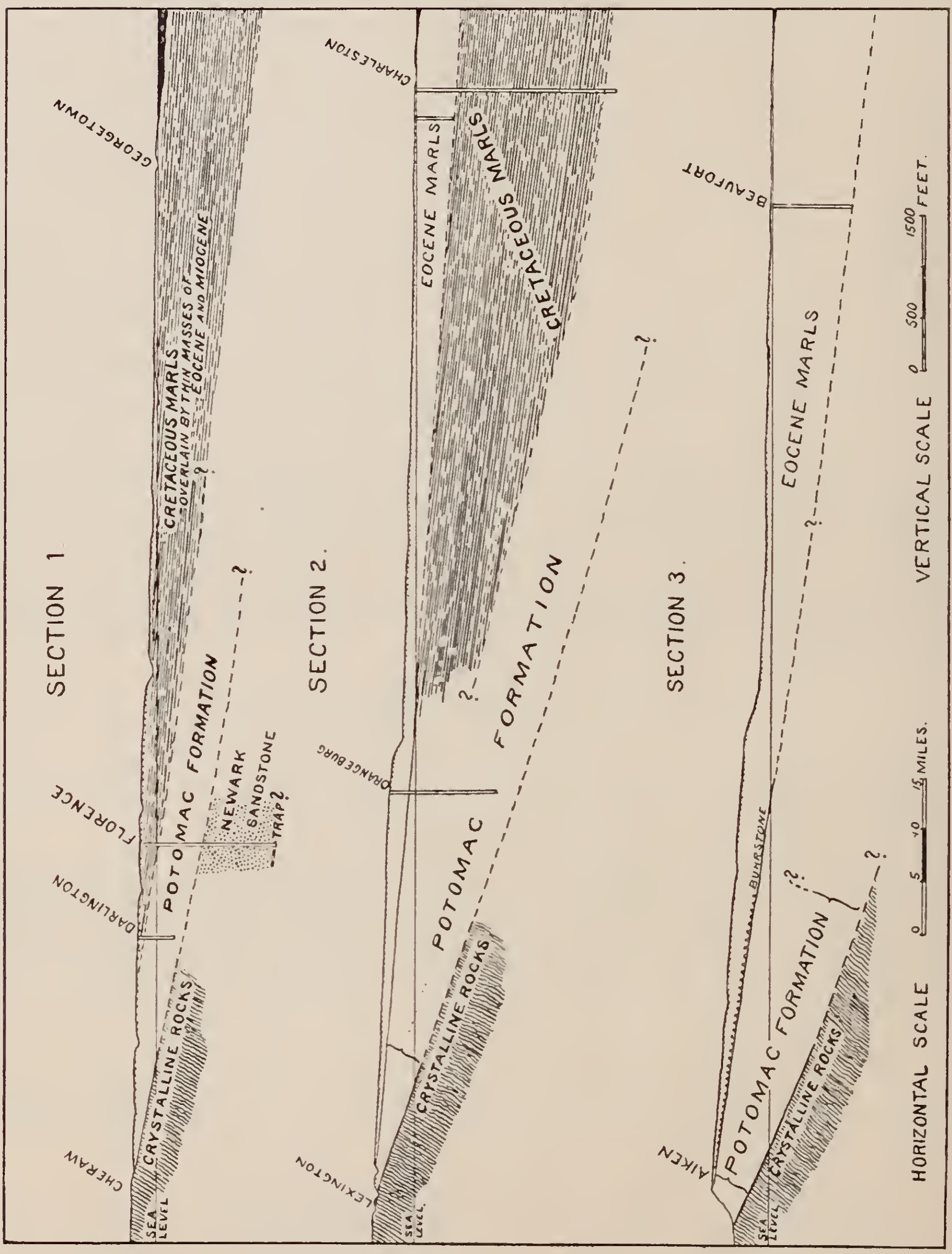

Figure 2.—*Sections across the Coastal Plain Region in South Carolina.*

overlain by the Eocene buhrstone to the southward and by the marls of the marine Cretaceous north of the Wateree river. The formation is, however, very irregular in stratigraphy, and clays occur at low horizons at some points, while near Congaree creek, south of Lexington, I observed the Eocene beds lying on cross-bedded sandstones which merge into a kaolinic arkose on the one hand and into white clays on the other. This kaolinic arkose, as I have termed it, is a remarkable rock. It is pure white in color, and although quite hard it contains a very large proportion of true kaolin, intermixed with quartz-sand and much white mica.

The Potomac outcrops which I visited are at Hamburg, opposite Augusta; Aiken; Congaree creek, near Lexington; Columbia; the region about the junction of the Wateree and Congaree rivers; Camden, and Cheraw, and I made a boat voyage down the Peedee river from Cheraw to Mars bluff.

The exposures about Hamburg extend for about a mile along the face of the steep slope which rises from the edge of the flood-plain of the Savannah river to the general plateau level above. To the westward the underlying crystalline rocks may be seen rising gradually above the river, with an irregular shoreline, and the feather edge of the Potomac formation was found near the upper bridge to Augusta. The high plateau has a heavy mantle of typical orange loam of the Lafayette formation which extends for some distance west of Hamburg over the crystalline rocks. The Potomac beds consist of a great mass of irregularly cross-bedded, light colored sands containing scattered pebbles of quartz and occasional scattered streaks of sandy pebble beds. To the eastward as the upper beds come in they are seen to be finer grained and to include beds and streaks of light colored clays, sands and sandy clays. Farther down the river there are occasional showings of the formation, notably at Silver bluff and up Hollow creek, which empties into the river in this vicinity. In these exposures Tuomey has described beds of darker clays, and lignite deposits.

At Aiken there are excellent exposures of the Potomac beds in the railroad cuts. They extend from the granite in the valley of Horse creek to the heavy mantle of Lafayette formation which caps the high plateau on which the town of Aiken is built. The Potomac materials are similar to those exhibited along the Savannah river, but are all of light color. Some of the lower beds are lithified. At the top there is a bed of white sandy clay, about 30 feet thick, which is locally termed chalk. I was unable to find the western edge of the Eocene buhrstone along the face of the slope at Aiken, as reported by Tuomey, but it is found in wells and depressions a short distance eastward.

Along Congaree creek, six miles southeast of Lexington station, Potomac clays, sands and sandstones are extensively exhibited, notably at the "Rock house," which is an irregular line of cliffs of sandstone. This sandstone is partly of the kaolinic character described above. Tuomey reported fossils in the upper beds in this vicinity, but stated that they were too fragmentary for identification. I made a long search for organic remains over a considerable area about the "Rock house," but found nothing of molluscan nature. Portions of the soft, kaolinic sandstone show impressions of mica plates, which are often quite large and so curved as to suggest impressions of fragments of shells, but they are clearly not of organic origin. The edge of the buhrstone was found at a short distance south, lying on white clays and sands of typical Potomac character.

In the immediate vicinity of Columbia there are several small outcrops of the Potomac beds presenting the usual characteristics. Down the Congaree there are exposures in many small side branches, particularly in those which flow from the southward. These head in a plateau of Eocene overlain by the Lafayette formation, and they cut more or less deeply into clays and sands of the Potomac formation before they reach the low, swampy flats adjoining the river. At Fort Motte there is a high bluff lying a short way back from the river, in which the Potomac beds are seen overlain by the Eocene marls and dark clays containing abundant fossils.

In my trip down the Peedee river from Cheraw I traveled in a small skiff, and although I made a careful search for outcrops I found very few. It was not long after a freshet and the water was still quite high, so that possibly a greater number of exposures would have been seen at low water. Low banks of Columbia formation and wide areas of swamps were the only features that I observed excepting a short scarp at Gardners bluff, 10 miles below Cheraw, and Hunts bluff, 20 miles farther down. In Gardners bluff the following section was noted:

1.	Orange and buff sand loam	5 feet
2.	Orange sand with pebbles, cross-bedding	6 "
3.	Coarse gray sand with buff streaks	5 "
4.	Coarse gray sand, somewhat cross-bedded; lines of clay and quartz pebbles	10 "
5.	Fine gray sandy clay, massive; contains indistinct lenses of purer clay	8 "

Numbers 2 and 3 are sharply separated throughout by a slightly waving line; numbers 4 and 5 are separated by a moderately sharp break, which is quite irregular at several points. Beds 1 and 2 are probably Lafayette in age and the underlying deposits are undoubtedly Potomac formation. At Hunts bluff there is a 20-foot exposure for about 200 feet along the northeast bank of the river. At its base it exhibits gray, cross-bedded sands, with a few scattered quartz pebbles; next there is an irregular bed of pebbly sands and then stratified gray to brown sands, merging upward into brown-buff loams at the surface. The basal beds appear to be Potomac, but the evidence is not conclusive. A short distance eastward in the higher lands about Bennettsville there are observed the marls of marine Cretaceous age, which overlies these Potomac beds. The marls come to the river bank at Mars bluff, below the railroad bridge, 10 miles east of Florence, in a fine series of exposures which have been briefly described by Tuomey. The Potomac beds there are sands and clays of the usual character, and they pass beneath the river a short distance below. The marine Cretaceous marl and marlstone contain abundant distinctive fossils, and they are in turn overlain by fossiliferous Eocene marlstone for some distance.

Several deep wells in South Carolina have penetrated the Potomac beds and their records throw some additional light on the relations. The well in the village of Aiken was bored through the formation at a point near the western edge of the Eocene, and consequently it exhibits the full thickness of the Potomac. The following record is given:

0–45	feet	red clay. Lafayette.	Potomac.
45–100	"	sand.	
100–130	"	"chalk." Mixture of fine white sand and kaolin.	
130–465	"	sand and soft sandstone; some clay.	
465–741	"	granite.	

A well at Florence, having a depth of 1,335 feet, passed through Miocene, marine Cretaceous and Potomac formations, and at 608 feet entered typical red sandstone of the Newark formation. The Potomac beds begin at a depth of about 110 feet, as nearly as I can recognize them, and consequently have a thickness of about 500 feet. They consist of gray sands in greater parts, presenting considerable variety in coarseness. Considerable lignite was reported, but no clay appeared in the few samples of borings which were saved. For the well at Marion I was unable to obtain many definite data, but learned that the lower members of the Coastal Plain series were alternating beds of sand and tough clay, and that their floor of crystalline rock was found at a depth of 700 feet. At Darlington the Potomac sands were found underlying the Cretaceous marls, but the depth of the contact was not ascertained. At Orangeburg the Potomac sands were entered for some distance in a well which has a depth of 1,160 feet. I was only able to obtain meager information for this well, and could not determine the nature or age of the beds which lie next above the Potomac sands, but I should expect them to include a considerable portion of the marine Cretaceous marls which extend from 430 to over 1,800 feet in the Charleston well. I might here add that I am strongly inclined to believe that at least a portion of the lower beds in the Charleston wells may represent an offshore phase of the Potomac formation. However, as higher Cretaceous molluscan remains were reported from a depth of 1,955 feet in the first well, the water-bearing sands and sandstones from 1,960 to 1,980 feet may be the top of the Potomac formation.

Although I observed plant remains in the Potomac beds at many points * which would no doubt settle any question as to the age of the beds, I have depended entirely on the structural relations and physical characteristics for my correlation of the formation. There could not be any doubt as to the continuity of the great series of sands, clays and sandstones which underlie both the Eocene buhrstone and the Cretaceous marls and lie on the surface of the crystalline rocks. As this series lies below quite old marine Cretaceous and above the Newark formation, the most obvious correlation would be with the Potomac formation, which occupies this position for hundreds of miles along the Atlantic slope, and moreover their physical characteristics fully bear out the correlation. Of course in speaking of the Potomac formation I refer to that formation as a whole, comprising the Tuscaloosa beds, which I believe are eventually to be separated as an independent formation.

Marine Cretaceous Formation

I have nothing of general interest to add to the statements of Tuomey regarding the Cretaceous marls and clays, for I did not extend my observations very far into their area. The formation appears to thin out before reaching the Wateree river, and on Black river it appears to be buried under the Tertiary, excepting possibly for a short distance near Kingstree, where it is indicated on the geologic map issued in 1883. The enormous expansion of the formation in the well at Charleston is a rather surprising feature, but, as above suggested, it is possible or even probable that the lower beds in this well are offshore deposits of Potomac age.

Eocene Formations

The lowest Eocene beds westward are the buhrstone and some argillaceous marls which underlie the buhrstone at certain localities. To the eastward there are sev-

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* I have been informed by Professor Lester F. Ward that he has discovered plant remains of Potomac age in the extension of these beds in North Carolina on the Cape Fear river and also at various points in eastern Alabama.

eral hundred feet of overlying marls, and the buhrstone appears to lose its characteristics in the extreme eastern part of the state. In the northern portion of the state the Eocene formations thin rapidly as the marine Cretaceous beds rise to the surface, and they are finally represented by thin outliers, often lying quite widely scattered over the irregular surface of the Cretaceous marls. The western edge of the buhrstone passes from Aiken to within 10 miles of Columbia, and thence to the eastward to below the confluence of the Congaree and Wateree rivers. In the wells at Charleston the Eocene members have a thickness of about 370 feet, and are supposed to lie at about 60 feet below the surface. They there consist of marls of various kinds, which are mainly argillaceous above and more calcareous below. The buhrstone is a very hard silicious rock, often 15 to 20 feet thick, and usually filled with shells. The overlying marls and marlstones are known as the Santee beds, which consist mainly of light colored marls, with some beds of marlstone of considerable extent, and the Ashley and Cooper marls, which are of darker color.

Miocene Formations

The Miocene deposits consist of sands and marls, which occur in scattered areas mainly in the northern and eastern counties. Lately Dr Dall has found evidence that the phosphate deposits are also of this age. The thickness of the sands and marls is usually not over 30 feet, and they lie on an irregular surface of the Eocene or marine Cretaceous formations.

Lafayette Formation *

This is a superficial mantle of orange sands and loams which covers the higher plateau regions. The elevation of this plateau is about 650 feet along the western border of the coastal plain. There it has a thickness of from 30 to 80 feet, and its more loamy portions give rise to the greater part of the "Red Hills." Its eastern extension has not been traced, but it is thought to be the same as some of the younger Pliocene marls.

Columbia Formation

This is a thin capping, mainly of sands and loams, which covers the lower lands and appears to extend as high as 400 feet or more in the higher region, giving rise to some portions of the "Sand hills."

RÉSUMÉ OF GENERAL STRATIGRAPHIC RELATIONS IN THE ATLANTIC COASTAL PLAIN FROM NEW JERSEY TO SOUTH CAROLINA

BY N. H. DARTON

Remarks were made by D. W. Langdon, Jr. An abstract of the latter paper is published in the American Geologist, volume xvii, page 108.

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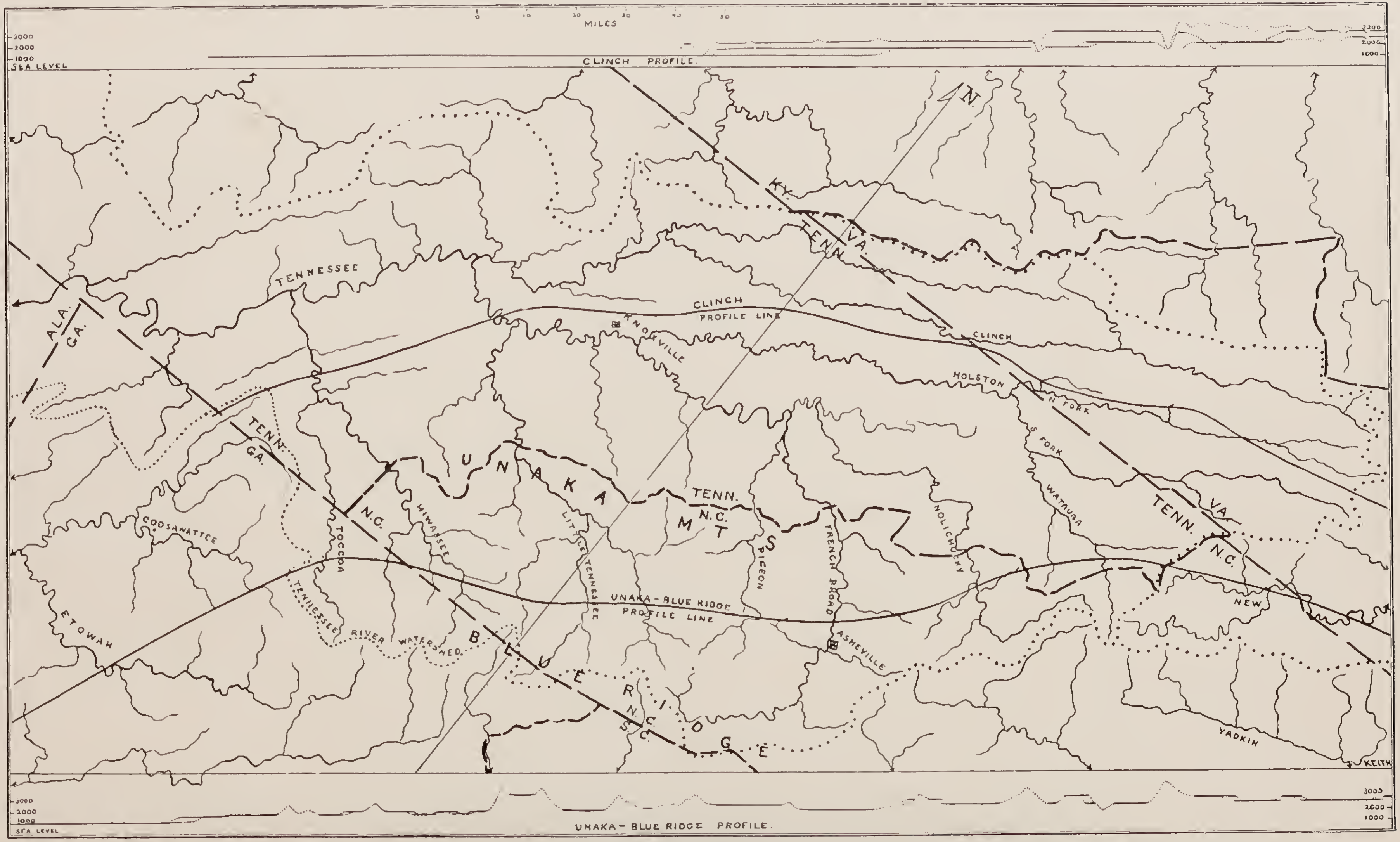
* Described at several localities by McGee. Twelfth Annual Report of the Director of the U. S. Geol. Survey, 1892, pp. 347–521.



THE TENNESSEE BASIN

The following paper was then read:

SOME STAGES OF APPALACHIAN EROSION

BY ARTHUR KEITH

Contents

INTRODUCTORY

In the southern Appalachians the phenomena of subaerial erosion are shown under every phase except those of arid and glacial conditions and in nearly every stage of development from alpine forms to complete reduction. The work of degradation, which is controlled by the characteristic features of Appalachian structure and stratigraphy, itself emphasizes these features most strongly. Various publications have been made of facts and theories connected with the erosion and uplift of the Appalachians. Willis * has described a characteristic Appalachian baselevel plain; Davis † has published theories and descriptions of peneplains in New Jersey and Pennsylvania; Hayes and Campbell ‡ have published a description, with a theory of the deformation of two peneplains shown at intervals over the southern Appalachians; the present author § has described the nature and deformation of five Appalachian peneplains in northern Virginia and Maryland, and various other publications have touched upon minor features of erosion. The subject is still far from fully grasped, however, and even the broad processes of the production of the present surface are a subject for discussion. The purposes of this paper are to classify the peneplains of the southern Appalachians according to the ideas expressed previously by the author, and to oppose the extreme application of the theory of deformation as advanced by Messrs Hayes and Campbell. For these objects a systematic presentation of details need not be given.

GENERAL FEATURES OF THE SOUTHERN APPALACHIANS

DRAINAGE BASINS

Four great groups of streams drain the southern Appalachians and are carrying on the work of erosion. First of these are the tributaries of the Tennessee river

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* National Geographic Magazine, vol. i, no. 4, pp. 291–300.
Ibid., vol. i, 1889, pp. 183–253.

† Proc. Bost. Soc. Nat. Hist., vol. xxiv, 1889, pp. 365–423.
National Geographic Magazine, vol. ii, 1890, pp. 81–110.
Bull. Geol. Soc. Am., vol. 2, 1890, pp. 545–581.

‡ National Geographic Magazine, vol. vi, 1894, pp. 63–126.

§ Fourteenth Annual Report of the Director of the U. S. Geol. Survey, 1892–93, pp. 366–394.

draining into the Ohio river from northern Alabama, Tennessee, southwest Virginia and western North Carolina; these streams head upon the Blue Ridge, flow northwest through the Unaka mountains, southwest along the Great valley of Tennessee and Virginia and northwest through the Cumberland plateau. The second group form the drainage of the Ohio river in southwest Virginia, West Virginia and Kentucky; these flow northwest in converging lines through New river and various arms of the Ohio. Third are the streams of middle and northern Virginia, Maryland and Pennsylvania, such as the James, Potomac and Susquehanna. The fourth, or Atlantic group, comprises streams rising east of the mass of the Appalachians and flowing directly into the Atlantic and the gulf of Mexico through eastern Virginia, North Carolina, South Carolina, Georgia and Alabama. Their waters run southeast into the Atlantic and south into the gulf of Mexico.

SURFACE FORMS

The typical surfaces produced by the cutting of these streams are well known through literature and need only a brief mention here. In the Great valley a series of long, straight valleys alternate with straight, narrow ridges. As compared with their length, the valleys are narrow, even when most conspicuous in size. In the Unaka mountains and Cumberland plateau the divides are irregular, the valleys show little systematic arrangement beyond a normal convergence into the great rivers, and the basins are broad in comparison with their width. Divides of the Atlantic drainage have small relief except near the stream heads, and the streams drain comparatively narrow, parallel basins.

Two general types of divides exist—those whose summits rise to nearly equal heights and those which show great diversity. The latter prevails in the Unaka mountains and along the borders of the chief river systems. The characteristic, even crests prevail in the vicinity of the larger streams in all regions and are most pronounced in the Atlantic drainage, the Great valley and the Cumberland plateau. Thus upon a broad view the Appalachians are most uniformly reduced near the larger streams and are most irregular near the major divides. Such a result is normal in ordinary erosion and would be expected in this case.

As deduced in theory and as exhibited in the Appalachians in hundreds of cases, erosion produces a regular sequence of forms. Beginning on an unreduced surface, a stream cuts a narrow trench steadily downward until it reaches its baselevel of erosion. Then the sides of the canyon are attacked, the downward cutting extending meanwhile up the larger and smaller tributaries until an approximate baselevel grade is established, increasing in slope as the streams diminish in power. Continued wear opens out the canyons into valleys and peneplains, which in time occupy the entire area adjacent to the larger streams and extend up the tributaries. Toward the heads of the streams these peneplains contract into valleys with floors rounding upward at their borders, and these in turn give place to series of terraces and bottoms. With the division and weakening of the streams, debris becomes coarser near its source, the little falls over individual pebbles accumulate into steeper grades, bottoms are replaced by planation slopes, and these by ravines and gullies. Above all project the unreduced masses or residuals forming the main divides. The details and successive steps of this process can be seen to perfection in the streams flowing into the Atlantic, and are there rendered especially clear because the streams flow over rocks of quite uniform powers of resistance. There the uniformity and omnipresence of the concave curve establish it beyond a doubt as the law, and the variation of the altitudes, hand in hand with the cutting power of the streams, defines the whole series as the result of subaerial erosion. In the Cumberland plateau the appearance of peneplains is often simulated by the outcrop of flat beds of hard rock which may lie at various altitudes and represent no period of reduction. In the Great valley also the peneplains are overshadowed and masked by the great differences of the rocks in point of resistance to wear. When once the criteria are established, however, it needs no extended search to discover successive forms of degradation as distinct as in the Atlantic streams and grouped in the same manner. Difficulties in the paths of the streams are more localized, however, by the differences in the rocks, and need consideration in coördinating the forms.

VARIATIONS OF LEVEL

During any extended period of degradation minor difficulties of erosion would be reduced, but the major barriers, such as are produced by unusual groups of rocks and affect entire river basins, can retard reduction so seriously as to produce considerable discordance of elevation in different basins. An excellent instance of this is furnished by the Pigeon and French Broad rivers in North Carolina. These streams flow in concentric curves, and the larger or French Broad meets the least obstruction; it has accordingly reduced its peneplains and valleys which lie above the barrier 400 feet lower than the corresponding ones of the Pigeon. Results in the same direction would ensue from warping of the surface, which would give added slope and power to one stream and decrease the grade of an opposite flowing stream. This would retard final reduction merely by the added amount of material to be removed, but would leave no permanent differences of altitude in similar forms. An unfailing factor in producing differences of altitude at like periods of reduction is the distance from the sea. A peneplain produced by a stream 500 miles from its mouth will be higher than one produced only 100 miles from the sea, whether by the same or a different stream and whether in the same or a different region. A certain amount of fall, however slight, is necessary to make the rivers flow and will be expressed in the accumulated altitudes. On this account the Yadkin river, flowing direct to the Atlantic, has formed its peneplain at 2,300 to 2,500 feet close up to the main residual of the Blue Ridge, while the Nolichucky, 30 miles to the west, taking a longer course through the Tennessee, has cut its peneplain along its main valley only down to 2,600, or 200 feet higher.

Most potent of all factors of variation is the amount and nature of debris furnished to the streams. Insoluble rocks clog the streams with debris and large residuals furnish great quantities of waste, so that, as residuals in general are composed of the more obdurate strata, the two unite to raise the grades and perpetuate divides. Soluble rocks yield debris which moves with a minimum grade, so that they seldom remain as residuals. Accordingly grades over soluble rocks are low entirely to the divides, which are thus at the mercy of local variations in the rocks and in the stream powers, and which are correspondingly unstable.

It is to be expected, therefore, that widely dissimilar basins will have peneplains formed at the same time but at somewhat different altitudes. Such expectation is amply borne out by the facts of the field, and is in fact exceeded. The least inspection of peneplains shows differences of altitude amounting to 3,000 feet. Two explanations can be made of such great differences, either that one or two peneplains have been warped out of their original plane or that many peneplains are represented which were produced at different periods and successively elevated with little warping.

Features of the Tennessee Basin

PENEPLAIN GROUPS

Inspection of the Tennessee basin in the Great valley reveals well developed peneplains at four altitudes. The uppermost series appears in peneplains and plateaus near the heads of the main streams from 3,300 to 3,700 feet high, falling slightly away from the divides. As the streams increase in size these plains are more and more dissected by sharp gorges of later origin, until along the northwest front of the Unakas only the most insoluble rocks approximate the original height at 3,000 to 3,200 feet. In the valley of Tennessee some ridges of hard rock remain at this height, but are considerably dissected. On Cumberland plateau northwest of Knoxville a large area of knobs and level ridges on one of the main divides remains at 3,100 to 3,200 feet. As the draining streams grow larger this ancient plain is dissected and supplanted by another and lower plain.

This second great group of forms is found at altitudes of 2,000 to 2,600 feet. It begins as a series of peneplains along the upper Holston at 2,300 to 2,500 feet. Behind the barrier of the Unakas the tributaries of the Tennessee, the Nolichucky, French Broad and Pigeon rivers, have cut out broad peneplains from 2,300 to 2,700 feet. These are very well preserved, and in every case they show a slight but steady rise upstream, whatever the direction of flow. As before stated, the Pigeon peneplain is uniformly higher than the adjacent French Broad plain. Passing down the Great valley the second peneplain is much dissected, and appears only in sandstone ridges in the valley or in peneplain remnants along the foothills of the Unaka mountains at elevations ranging from 2,100 to 2,400 feet. The Clinch and Bays mountains and the Cumberland front, especially the former, are fine examples of baseleveled ridges. In the lower Tennessee valley all traces of this peneplain have been removed.

The third group of surface forms attains prominence in the Tennessee valley after the confluence of Watauga river and the north and south forks of Holston river at altitudes of 1,600 to 1,800 feet. Above the junction it is only manifest in broad flood-plains, bottoms and similar features fingering between the remnants of the peneplain last described. For 50 or 60 miles southwest down the valley this altitude of 1,600 to 1,800 feet is prominent in broad peneplains. These become more and more dissected, until only scattered ridges attain that height, and the country stands at 1,000 to 1,100 feet. Along either side of the Great valley many remnants of this peneplain appear; on the Hiawassee drainage through the Unakas it is finely developed at 1,700 to 1,800 feet, and on the opposite side of the valley Waldens ridge and Cumberland plateau exhibit broad areas at 1,500 to 1,700 feet.

The last series appearing in the Tennessee valley becomes predominant after the union of Nolichucky, French Broad and Holston rivers above Knoxville. Broad bottoms and gravel-covered terraces and valleys mark the emergence of the rivers at 1,000 feet, their courses between that altitude and 1,600 to 1,800 feet being largely confined to narrow valleys and gorges. Below these points broad valleys appear, widen out into peneplains and soon occupy the entire valley at 1,000 to 1,100 feet, extending southwestward at that height for many scores of miles. In the course of still more recent erosion the streams have carved narrow canyons, which slowly open out downstream and are bordered by terraces and bottoms from 600 to 700 feet above sea.

Thus in the Tennessee valley are seen four distinct groups of peneplains and associated features, marking four periods of stable land and long degradation. The greatest of these is the first, because it extended to the headwaters of the main rivers, and only the most obdurate and remote masses escaped reduction. Each successive period was less important than the preceding as measured by the results accomplished. The forms of any minor period would have been obliterated, however, by a greater subsequent one, so that the record can only be expected to preserve those which were in descending order of magnitude. At the present day the most conspicuous are the 1,600 to 1,800 and the 1,000 to 1,100-foot peneplains, which occupy much of the Great valley, and, swinging around the south end of the Unaka mountains and the Blue ridge, pass northeast along the heads of the Atlantic basins.

CLINCH SECTION

The relations of Clinch mountain, the typical baseleveled ridge of Tennessee, furnish an epitome of the whole basin. Rising abruptly from the 1,000-foot peneplain and flanked on both sides by ridges of the next peneplain at 1,600 to 1,700 feet, its summits stand at 2,100 to 2,200 feet; a few points rise to 2,500 feet and a few wind gaps are cut down to 2,000 feet. This average height of 2,200 feet is maintained for 100 miles northeastward to Moccasin gap, near the state boundary in Virginia, the flanking ridges continuing at uniform heights. Northeast of that gap the mountain rises within three miles to 3,200 feet, and its summits continue at that height for 30 miles to Little Moccasin gap. From this point northeastward the mountain is very irregular in height and loses its identity in a great mass, which is for the most part over 4,000 feet above the sea. In this group of ridges the 1,000-foot peneplain is perfectly obvious; the same characteristics that are conceded to Clinch mountain at 2,200 feet are precisely repeated in the portion standing at 3,200 feet and in the flanking ridges at 1,600 feet. Therefore the same reasoning that identifies a baseleveled ridge at 2,200 feet must recognize the abruptness of the jump from level to level and must identify three baselevel periods instead of one. The linear profiles of the ridges are shown on the accompanying map.

UNAKA-BLUE RIDGE SECTION

A profile with similar features but less compact in form is taken along the headwaters of the Tennessee branches between the Blue Ridge and the Unaka mountains. It starts with a series of plateaus in Virginia and North Carolina, near the state boundary, at heights of 3,100 to 3,200 feet. These are considerably interrupted by the residuals between the Ohio streams and the Tennessee basin, but can readily be traced over into the Tennessee basin at heights of 3,300 to 3,500 feet. Into this surface are sunk the fingers of the lower system at 2,600 to 2,700 feet. On this part of the section the peneplains are much interrupted by residuals, and on the divides between the Watauga-Nolichucky and the Nolichucky-French Broad basins the upper peneplain again appears. The second plain is well shown in the French Broad and Pigeon basins at 2,200 and 2,600 feet, and again on the Tuckaseegee at 2,300 and the Little Tennessee at 2,200 to 2,100 feet. The Nantahalah has barely produced a plain at the upper level of 3,500 to 3,600 feet, while into the edges of this the two Hiawassee peneplains are cut at 2,100 feet and at 1,800 to 1,900 feet, with bottoms and terraces sloping up the streams. These plains with small residuals continue in the Nottely and Toccoa basins, and the lower is carried on through the Etowah basin, descending to 1,700 and 1,600 feet. In the latter basin the 1,600-foot peneplain is shortly cut out by the 1,100 to 1,200-foot plain, which gradually descends to 1,100 and 1,000 feet with the fall of the river, continuing at that height for nearly 100 miles. In this section the abundance of residuals has necessarily increased the grades of the streams and produced the semblance of warped surfaces, but the abruptness of the breaks from plain to plain and the direction of the slope away from the divides in most cases remove the possibility of warping and make it necessary to distinguish the plains as separate.

Northwest of Knoxville, Tennessee, the four series show the well developed steps within a radius of eight miles, and in innumerable instances groups of three appear in close connection. In each group of forms the sequence from dissected peneplain through the peneplain into the broad valley, bottom and canyon is normal and complete, and the beginnings of each lower plain cut deep into the heart of the plain next above it. In its broad reaches each plain is remarkably constant in level, but in its narrow portions, where grades are raised by debris from neighboring residuals, the slope upstream is invariably found, regardless of the direction of flow. Areas occur in which peneplains are indubitably warped, but they are readily recognized on the ground and are distinctly the exception. In short, erosion has produced in this basin at least four peneplains, each approximately level and each swinging around the heads of the lower plains in successive steps.

SUMMARY

Study of other river basins reveals similar series in every case, and without citing the countless details thus far known it is sufficient to state in brief that Appalachian degradation was marked by at least seven periods of approximate reduction. Each of these produced a vast series of peneplains which appear in various forms at the present day; the oldest lie along the main divides and the youngest along the margin of the sea. In some cases these plains have been warped from their original level, but far the greater portions of them retain nearly their original attitudes. It follows, therefore, that the disturbances which caused the revival of erosion were characterized by broad, uniform uplifts with local zones of warping quite subordinate in area. This is typified by the peneplain in Maryland and eastern Virginia, which ranges for 100 miles east and west and many times that distance to the southwest at an altitude of 500 to 550 feet, but which along the Staunton river in southern Virginia slopes up northwest 400 feet in 30 miles and then remains level for the next 30 miles.

This view departs considerably from the theories of other authors, who have defined the peneplains as dome-shaped or warped surfaces, making the warping the predominant feature of the uplift. Further differences of view exist in the distinction of many peneplains instead of a few. It is agreed that the higher peneplains are associated with the main divides; that fact, however, is as well explained *a priori* by the usual sequence of erosion as by the theory of warping. The peneplains must have been deformed, otherwise the land never could have risen; but, on the other hand, the peneplains must rise with the streams and in regions of massive residuals with a considerable slope; therefore the differences of level must be studied in each group and may be referred to one or both causes. The normal peneplain surface is slightly sloping, and for each slope to which a different origin is ascribed proof must be furnished to account for the abnormal condition. The present confusion has been caused, in part at least, by correlating as parts of the same peneplain features which in the field can be traced past one another as parts of different peneplains. In other cases a peneplain actually slopes, but its slope is with the fall of the stream and in a direction contrary to that demanded by the extreme theory of warping. In short, the slopes of the peneplains are so slight in the great majority of cases as to distinguish warping as the exceptional form of uplift. Although the process was a simple one, the succession of uplifts was long and quite complex. A full understanding of the different stages demands the expenditure of much time and connected field work, and will be made the subject of future publications.

The following paper was read by title:

THE CERRILLOS COAL FIELD OF NEW MEXICO

BY JOHN J. STEVENSON

[*Abstract*]

During August, 1895, the writer had an opportunity to revisit the Placer coal field of New Mexico, now known as the Cerrillos coal field. It is about 25 miles south from Santa Fé and directly beyond the Galisteo river. The field is small, apparently a detached portion of the Laramie area extending far southward within the Rio Grande region.

The district of especial interest is that lying south from Cerrillos and Waldo, stations on the Santa Fé railroad. It is less than two miles wide, and reaches southward to little more than five miles from the Galisteo, but it contains evidently all of the workable coal beds, and exhibits the transition from bituminous to anthracite in a very satisfactory manner. The mines are all on Coal canyon, which extends from the Placer or Ortiz mountains at the south to Waldo at the north, somewhat more than six miles.

The Ortiz mountains are largely trachytic; from them there extend northward two plates, each about 200 feet thick, which pass between Laramie strata and follow very closely the dip of the stratified beds. The upper plate covers the area east from Coal canyon, and is now the surface rock, the overlying beds having been removed. It extends northward to somewhat less than two miles south of Waldo, terminating opposite the lower end of the village of Madrid, where are the offices of the Cerrillos Coal Company. The lower plate, about 400 feet below the upper, does not come to the surface on Coal canyon, but it was reached in a boring on the mesa immediately west and comes out in an arroyo within a few rods west from the boring. Several dikes extend upward from this plate, one evidently very large being shown west from Coal canyon, which must have been connected with the upper plate, as it rises very high above the mesa; a second is seen in Coal canyon, not more than 10 or 12 feet wide; it does not reach the upper plate; a third, very narrow, found in the same canyon at a mile and a half above Madrid, passes distinctly into the upper plate. Professor Kemp examined the specimens from several exposures and recognizes the close resemblance in composition throughout.

The only stratified rocks within the district examined belong to the Laramie, and the exposed section is somewhat more than 1,000 feet thick. The rocks resemble those of the same age in the Trinidad coal field, but shale is present in greater proportion. Limestone is wholly absent, apparently, and the sandstones are unusually non-fossiliferous. The coal beds are numerous, but most of them are very thin and several are not persistent in all of the sections.

The only coal beds of interest here are those within the interval between the trachyte plates. They are

White-ash coal bed	2 feet 6 inches to 7 feet.
Interval	70 "
Coking coal bed	1 foot to 2 feet 6 inches.
Interval	80 feet.
Cook-White coal bed	3 "
Interval, about	150 "
Waldo coal bed	4 "

The White-ash bed is not more than 15 feet below the upper plate, and the Waldo bed as found in the bore-hole about 10 feet above the lower plate of trachyte.

The White-ash bed has been mined at many pits along Coal canyon for a distance of nearly three miles, beginning at about a mile and a half from Waldo. It is the important bed of the region and the only one now mined. It was examined in four pits, two of which are now in operation. At the old Boyle mine, about a mile and a half above Madrid, the coal is a hard dry anthracite, varying much in character. It is slipped and jointed throughout. Some portions closely resemble the graphitoid anthracite of Rhode Island.

The Lucas mine at Madrid was idle when visited, but work had been stopped for only a short time. The southerly levels of this mine yield an anthracite of excellent quality, equal in appearance and composition to the average anthracite of Pennsylvania, but the northerly levels show a rapid change. Jointing becomes annoying at a little distance from the slope and the coal is wasted in the breaker. Within 350 feet evidences of great pressure and disturbance accumulate and the coal soon is laminated, like that from some Vespertine mines of southwest Virginia, with the polished surfaces, often curved, frequently not more than one-fourth of an inch apart. This, however, is still anthracite, and work was stopped in these northerly levels only because of great waste in breaking.

The Cunningham mine, at the lower end of Madrid, entered a tender coal at the crop; the slope was pushed 1,100 feet, but no anthracite was found. The coal burns with flame.

The White-ash mine, about half a mile north from the Lucas, is the important pit. At one time trains might be seen coming from its slope made up of cars carrying, some of them, anthracite, others the tender, semi-bituminous, and others still the rich bituminous coal which has given this mine its reputation. The bituminous coal, containing 39 per cent of volatile combustible, is obtained from the northerly levels, but the southerly levels yield for the most part what is called tender coal. The latter is dull, very tender and much of it has an almost cone-in-cone structure. It is reached in the southerly levels at varying distances from the slope. The passage from bituminous into anthracite through this tender coal is shown in the sixth level, southerly, where the tender coal was reached at 125 feet from the slope and the anthracite at 450 feet. The passage is gradual. The anthracite makes its appearance at the bottom and thickens gradually, crushed coal being replaced by laminated and that by the harder almost homogeneous coal, the change being completed within 50 feet.

The Coking bed was worked some years ago at about two miles above Madrid, where its coal was coked in ricks.

The Cook-White coal is no longer mined, but it has been opened at many places along Coal canyon, and the changes in character of the coal are clearly shown.

Above Madrid fragments on the old dumps show that the coal is anthracite. A pit at the lower end of Madrid, almost midway between the Cunningham and White-ash mines, shows a tender coal which resembles that from Pocahontas, in Virginia. Analysis shows that it contains about 30 per cent of volatile, which is about what should be expected if its changes are similar to those of the White-ash.

The Waldo bed is not reached in the upper part of Coal canyon, but it has been mined extensively further down. The only interest it has here is its existence in the bore-hole west from Coal canyon, where it is not more than 10 feet above the lower plate of trachyte, and shows no evidence of any metamorphism whatever.

Long ago Newberry and afterward Stevenson regarded the coal as metamorphosed by heat from a great dike of eruptive rock following the northerly side of the Placer (now Ortiz) mountains. This, which then was but a suggestion, is sufficiently clear as an explanation now. As the center of eruption was in the Ortiz mountains, the metamorphism should be most notable near those mountains. That is distinctly the condition, for at the most southerly point showing the White-ash bed well the anthracite is very hard, but the change is less and less toward the north until normal coal is reached in the White-ash mine below Madrid. The gradation is equally clear in the Cook-White bed, but the small bed between the main seams appears to contradict the hypothesis, as it is decidedly bituminous at half a mile above the pit where the White-ash bed yields the hardest anthracite observed. This condition is easily explained by the fact that the small bed is broken by clay seams several feet wide, which sometimes cut out all of the coal; these seams would prevent the passage of heat from one portion to another.

The conditions at several localities show that mere proximity to the mass of eruptive rock was insufficient to produce change. The lower plate of trachyte is but 10 feet below the Waldo coal bed in the bore-hole west from Coal canyon, but, though 200 feet thick, it had no appreciable effect upon the coal. The interval between the White-ash bed and the upper plate of trachyte shows insignificant variations along Coal canyon, and it must be approximately the same in the newer parts of the White-ash mine, yet in the Lucas mine and at all localities south from it the coal is anthracite, whereas at all points north from it to the border of the eruptive rock one finds only transition coal. It seems clear that direct contact is necessary to produce change.

Professor J. F. Kemp describes the eruptive rock as a trachyte closely allied to andesite. Its outflow then was early, possibly at the time of the Laramide elevation, when great outpourings of andesite occurred in Colorado, Utah, Wyoming and Montana. The coal was completely formed prior to this elevation, prior to any disturbance, there being not only no evidence of pulpiness, but every evidence that the coal was thoroughly hard. It was crushed into minute fragments, slickensided like the Utica shales of Franklin county, Pennsylvania, or laminated and rolled into leaves like the Vespertine coals of southwestern Virginia. The process of conversion was complete before disturbance, not merely in the lowest beds, but also in the White-ash bed at nearly 900 feet above the bottom of the Laramie.

The scientific program was declared finished. Vice-President Charles H. Hitchcock offered the following resolution, which was unanimously adopted:

"*Resolved*, That the sincere thanks of the Geological Society of America are hereby tendered to the officers of the University of Pennsylvania for their kindness and courtesy, particularly in granting the use of rooms in the Department of Arts building and for the midday luncheon; also to the 'Local Committee' for their efforts to make the meeting a success."

With a few appropriate remarks, the President declared the meeting adjourned.

Register of the Philadelphia Meeting, 1895

The following Fellows were in attendance at the meeting:

Florence Bascom.
Robert Bell.
A. S. Bickmore.
H. D. Campbell.
M. R. Campbell.
W. B. Clark.
E. D. Cope.
Whitman Cross.
N. H. Darton.
W. M. Davis.
J. S. Diller.
E. V. d'Invilliers.
E. T. Dumble.
B. K. Emerson.
S. F. Emmons.
H. L. Fairchild.
Persifor Frazer.
G. K. Gilbert.
F. P. Gulliver.
C. W. Hayes.
Angelo Heilprin.
C. H. Hitchcock.
Jed. Hotchkiss.
E. O. Hovey.
L. L. Hubbard.
J. P. Iddings.
R. T. Jackson.
Arthur Keith.
J. F. Kemp.
C. R. Keyes.
A. C. Lane.
D. W. Langdon, Jr.
Frank Leverett.
F. J. H. Merrill.
Edward Orton.
L. V. Pirsson.
H. F. Reid.
W. N. Rice.
Heinrich Ries.
R. D. Salisbury.
Charles Schuchert.
W. B. Scott.
N. S. Shaler.
C. H. Smyth, Jr.
J. Stanley-Brown.
T. W. Stanton.
J. J. Stevenson.
J. A. Taff.
R. S. Tarr.
C. R. Van Hise.
M. E. Wadsworth.
W. H. Weed.
I. C. White.
H. S. Williams.
Bailey Willis.
J. E. Wolff.
G. F. Wright.

Fellows-elect

H. F. Bain.
H. B. Kümmel.
F. B. Taylor.
J. B. Woodworth.

Total attendance, 61.

OFFICERS AND FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA

OFFICERS FOR 1896

President

Joseph Le Conte, Berkeley, Cal.

Vice-Presidents

C. H. Hitchcock, Hanover, N. H.
Edward Orton, Columbus, Ohio.

Secretary

H. L. Fairchild, Rochester, N. Y.

Treasurer

I. C. White, Morgantown, W. Va.

Editor

J. Stanley-Brown, Washington, D. C.

Councillors

(Term expires 1896)

F. D. Adams, Montreal, Canada.
I. C. Russell, Ann Arbor, Mich.

(Term expires 1897)

R. W. Ells, Ottawa, Canada.
C. R. Van Hise, Madison, Wis.

(Term expires 1898)

B. K. Emerson, Amherst, Mass.
J. M. Safford, Nashville, Tenn.

FELLOWS, APRIL, 1896

*Indicates Original Fellow (see article III of Constitution)

FRANK DAWSON ADAMS, Ph. D., Montreal, Canada; Professor of Geology in McGill University. December, 1889.

TRUMAN H. ALDRICH, M. E., Birmingham, Ala. May, 1889.

HENRY M. AMI, A. M., Geological Survey Office, Ottawa, Canada; Assistant Paleontologist on Geological and Natural History Survey of Canada. December, 1889.

HARRY FOSTER BAIN, M. S., Des Moines, Iowa; Assistant Geologist, Iowa Geological Survey. December, 1895.

S. PRENTISS BALDWIN, Cleveland, Ohio. August, 1895.

ALFRED E. BARLOW, M. A., Geological Survey Office, Ottawa, Canada; Geologist on Canadian Geological Survey. August, 1892.

GEORGE H. BARTON, B. S., Boston, Mass.; Instructor in Geology in Massachusetts Institute of Technology. August, 1890.

FLORENCE BASCOM, A. M., B. S., Ph. D., Bryn Mawr, Penn.; Instructor in Geology, Petrography and Mineralogy in Bryn Mawr College. August, 1894.

WILLIAM S. BAYLEY, Ph. D., Waterville, Maine; Professor of Geology in Colby University. December, 1888.

*GEORGE F. BECKER, Ph. D., Washington, D. C.; U. S. Geological Survey.

CHARLES E. BEECHER, Ph. D., Yale University, New Haven, Conn. May, 1889.

ROBERT BELL, C. E., M. D., LL. D., Ottawa, Canada; Assistant Director of the Geological and Natural History Survey of Canada. May, 1889.

ALBERT S. BICKMORE, Ph. D., American Museum of Natural History, 77th St. and Eighth Ave., N. Y. city; Curator of Anthropology in the American Museum of Natural History. December, 1889.

WILLIAM P. BLAKE, Tucson, Ariz.; Professor of Geology, Metallurgy and Mining in University of Arizona. August, 1891.

*JOHN C. BRANNER, Ph. D., Stanford University, Cal.; Professor of Geology in Leland Stanford Jr. University.

ALBERT PERRY BRIGHAM, A. B., A. M., Hamilton, N. Y.; Professor of Geology and Natural History, Colgate University. December, 1893.

*GARLAND C. BROADHEAD, Columbia, Mo.; Professor of Geology in the University of Missouri.

HENRY P. H. BRUMELL, Ottawa, Canada; Manager of N. A. Graphite and Mining Company. August, 1892.

*SAMUEL CALVIN, Iowa City, Iowa; Professor of Geology and Zoölogy in the State University of Iowa. State Geologist.

HENRY DONALD CAMPBELL, Ph. D., Lexington, Va.; Professor of Geology and Biology in Washington and Lee University. May, 1889.

MARIUS R. CAMPBELL, U. S. Geological Survey, Washington, D. C. August, 1892.

FRANKLIN R. CARPENTER, Ph. D., Deadwood, South Dakota; Superintendent Deadwood and Delaware Smelting Company. May, 1889.

Robert Chalmers, Geological Survey Office, Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. May, 1889.

*T. C. Chamberlin, LL. D., Chicago, Ill.; Head Professor of Geology, University of Chicago.

Clarence Raymond Claghorn, B. S., M. E., Vintondale, Pa. August, 1891.

*William B. Clark, Ph. D., Baltimore, Md.; Professor of Geology in Johns Hopkins University.

*Edward W. Claypole, D. Sc., Akron, O.; Professor of Natural Science in Buchtel College.

Julius M. Clements, B. A., Ph. D., Madison, Wis.; Assistant Professor of Geology in University of Wisconsin. December, 1894.

Collier Cobb, A. B., A. M., Chapel Hill, N. C.; Professor of Geology in University of North Carolina. December, 1894.

*Theodore B. Comstock, Tucson, Ariz.; President of the University of Arizona.

*Edward D. Cope, Ph. D., 2102 Pine St., Philadelphia, Pa.; Professor of Geology in the University of Pennsylvania.

*Francis W. Cragin, B. S., Colorado Springs, Col.; Professor of Geology and Natural History in Colorado College.

*Albert R. Crandall, A. M., Milton, Wis.

*William O. Crosby, B. S., Boston Society of Natural History, Boston, Mass.; Assistant Professor of Mineralogy and Lithology in Massachusetts Institute of Technology.

Whitman Cross, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

Garry E. Culver, A. M., 1104 Wisconsin St., Stevens Point, Wis. December, 1891.

*Henry P. Cushing, M. S., Cleveland, Ohio; Associate Professor of Geology, Adelbert College.

T. Nelson Dale, Williamstown, Mass.; Geologist, U. S. Geological Survey, Instructor in Geology, Williams College. December, 1890.

*Nelson H. Darton, United States Geological Survey, Washington, D. C.

*William M. Davis, Cambridge, Mass.; Professor of Physical Geography in Harvard University.

George M. Dawson, D. Sc., A. R. S. M., Geological Survey Office, Ottawa, Canada; Director of Geological and Natural History Survey of Canada. May, 1889.

Sir J. William Dawson, LL. D., Montreal, Canada. May, 1889.

David T. Day, A. B., Ph. D., U. S. Geological Survey, Washington, D. C. August, 1891.

Orville A. Derby, M. S., Sao Paulo, Brazil; Director of the Geographical and Geological Survey of the Province of Sao Paulo, Brazil. December, 1890.

*Joseph S. Diller, B. S., United States Geological Survey, Washington, D. C.

Edward V. d'Invilliers, E. M., 711 Walnut St., Philadelphia, Pa. December, 1888.

*Edwin T. Dumble, Austin, Texas, State Geologist.

Clarence E. Dutton, Major, U. S. A., Ordnance Department, San Antonio, Texas. August, 1891.

*William B. Dwight, M. A., Ph. B., Poughkeepsie, N. Y.; Professor of Natural History in Vassar College.

Charles R. Eastman, A. M., Ph. D., Cambridge, Mass.; Assistant in Paleontology in Harvard University. December, 1895.

*George H. Eldridge, A. B., United States Geological Survey, Washington, D. C.

Robert W. Ells, LL. D., Geological Survey Office, Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. December, 1888.

*Benjamin K. Emerson, Ph. D., Amherst, Mass.; Professor in Amherst College.

*Samuel F. Emmons, A. M., E. M., U. S. Geological Survey, Washington, D. C.

John Eyerman, F. Z. S., Oakhurst, Easton, Pa. August, 1891.

Harold W. Fairbanks, B. S., Berkeley, Cal.; Geologist State Mining Bureau. August, 1892.

*Herman L. Fairchild, B. S., Rochester, N. Y.; Professor of Geology and Natural History in University of Rochester.

J. C. Fales, Danville, Kentucky; Professor in Centre College. December, 1888.

Eugene Rudolph Faribault, C. E., Geological Survey Office, Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. August, 1891.

P. J. Farnsworth, M. D., Clinton, Iowa; Professor in the State University of Iowa. May, 1889.

Oliver C. Farrington, Ph. D., Chicago, Ill.; In charge of Department of Geology, Field Columbian Museum. December, 1895.

Sandford Fleming, LL. D., Ottawa, Canada; Civil Engineer. August, 1893.

William M. Fontaine, A. M., University of Virginia, Va.; Professor of Natural History and Geology in University of Virginia. December, 1888.

*Persifor Frazer, D. Sc., 1042 Drexel Building, Philadelphia, Pa.; Professor of Chemistry in Franklin Institute.

*Homer T. Fuller, Ph. D., Springfield, Mo.; President of Drury College.

Henry Gannett, S. B., A. Met. B., U. S. Geological Survey, Washington, D. C. December, 1891.

*Grove K. Gilbert, A. M., United States Geological Survey, Washington, D. C.

Adam Capen Gill, A. B., Ph. D., Ithaca, N. Y.; Assistant Professor of Mineralogy and Petrography in Cornell University. December, 1888.

N. J. Giroux, C. E., Geological Survey Office, Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. May, 1889.

Charles H. Gordon, M. S., Beloit, Wis. August, 1893.

Ulysses Sherman Grant, Ph. D., Minneapolis, Minn.; Assistant on Geological Survey of Minnesota. December, 1890.

William Stukeley Gresley, Erie, Pa.; Mining Engineer. December, 1893.

George P. Grimsley, M. A., Ph. D., Topeka, Kan.; Professor of Geology in Washburn College. August, 1895.

Leon S. Griswold, A. B., 238 Boston St., Dorchester, Mass. August, 1892.

Frederick P. Gulliver, A. M., Cambridge, Mass. August, 1895.

*William F. E. Gurley, Springfield, Ill.; State Geologist.

Arnold Hague, Ph. B., U. S. Geological Survey, Washington, D. C. May, 1889.

*Christopher W. Hall, A. M., 803 University Ave., Minneapolis, Minn.; Professor of Geology and Mineralogy in University of Minnesota.

*James Hall, LL. D., State Hall, Albany, N. Y.; State Geologist and Director of the State Museum.

Henry G. Hanks, 1124 Greenwich St., San Francisco, Cal.; lately State Mineralogist. December, 1888.

John B. Hastings, M. E., Boisé City, Idaho. May, 1889.

John B. Hatcher, Ph. B., Princeton, N. J.; Assistant in Geology, College of New Jersey. August, 1895.

*Erasmus Haworth, Ph. D., Lawrence, Kan.

C. Willard Hayes, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

*Angelo Heilprin, Academy of Natural Sciences, Philadelphia, Pa.; Professor of Paleontology in the Academy of Natural Sciences.

*Eugene W. Hilgard, Ph. D., LL. D., Berkeley, Cal.; Professor of Agriculture in University of California.

Frank A. Hill, Roanoke, Va. May, 1889.

*Robert T. Hill, B. S., U. S. Geological Survey, Washington, D. C.

Richard C. Hills, Mining Engineer, Denver, Colo. August, 1894.

*Charles H. Hitchcock, Ph. D., Hanover, N. H.; Professor of Geology in Dartmouth College.

William Herbert Hobbs, B. Sc., Ph. D., Madison, Wis.; Assistant Professor of Mineralogy in the University of Wisconsin. August, 1891.

*Levi Holbrook, A. M., P. O. Box 536, New York city.

Arthur Hollick, Ph. B., Columbia College, New York; Instructor in Paleontology. August, 1893.

*Joseph A. Holmes, Chapel Hill, North Carolina; State Geologist and Professor of Geology in University of North Carolina.

Mary E. Holmes, Ph. D., 201 S. First St., Rockford, Illinois. May, 1889.

Thomas C. Hopkins, A. M., State College, Center county, Penn. December, 1894.

*Jedediah Hotchkiss, 346 E. Beverly St., Staunton, Virginia.

*Edmund Otis Hovey, Ph. D., American Museum of Natural History, New York city, Assistant Curator of Geology.

*Horace C. Hovey, D. D., Newburyport, Mass.

*Edwin E. Howell, A. M., 612 17th St. N. W., Washington, D. C.

Lucius L. Hubbard, A. B., LL. B., Ph. D., Houghton, Mich.; State Geologist of Michigan. December, 1894.

*Alpheus Hyatt, B. S., Bost. Soc. of Nat. Hist., Boston, Mass.; Curator of Boston Society of Natural History.

Joseph P. Iddings, Ph. B., Professor of Petrographic Geology, University of Chicago, Chicago, Ill. May, 1889.

Elfric D. Ingall, Geological Survey Office, Ottawa, Canada; in charge of Mineral Statistics and Mines. August, 1894.

A. Wendell Jackson, Ph. B., 407 St. Nicholas Ave., New York city. December, 1888.

Robert T. Jackson, S. B., S. D., 33 Gloucester St., Boston, Mass.; Instructor in Paleontology in Harvard University. August, 1894.

Thomas M. Jackson, C. E., S. D., Clarksburg, W. Va. May, 1889.

*Joseph F. James, M. S., Department of Agriculture, Washington, D. C.

*Willard D. Johnson, United States Geological Survey, Washington, D. C.

Alexis A. Julien, Ph. D., Columbia College, New York city; Instructor in Columbia College. May, 1889.

Arthur Keith, A. M., U. S. Geological Survey, Washington, D. C. May, 1889.

*James F. Kemp, A. B., E. M., Columbia College, New York city; Professor of Geology.

Charles Rollin Keyes, A. M., Ph. D., Jefferson City, Missouri; State Geologist. August, 1890.

Frank H. Knowlton, M. S., Washington, D. C.; Assistant Paleontologist U. S. Geological Survey. May, 1889.

Henry B. Kümmel, A. M., Ph. D., Trenton, New Jersey; Assistant on the State Geological Survey of New Jersey. December, 1895.

* George F. Kunz, care of Tiffany & Co., 15 Union Square, New York.

Ralph D. Lacoe, Pittston, Pa. December, 1889.

George Edgar Ladd, A. B., A. M., 81 Oxford St., Cambridge, Mass. August, 1891.

J. C. K. Laflamme, M. A., D. D., Quebec, Canada; Professor of Mineralogy and Geology in University Laval, Quebec. August, 1890.

Lawrence M. Lambe, Ottawa, Canada; Artist and Assistant in Paleontology, Geological Survey of Canada. August, 1890.

Alfred C. Lane, Ph. D., Houghton, Mich.; Assistant on Geological Survey of Michigan. December, 1889.

Daniel W. Langdon, Jr., A. B., 6 Wall St., New York city; Geologist of Chesapeake and Ohio Railroad Company. December, 1889.

Andrew C. Lawson, Ph. D., Berkeley, Cal.; Assistant Professor of Geology in the University of California. May, 1889.

* Joseph Le Conte, M. D., LL. D., Berkeley, Cal.; Professor of Geology in the University of California.

* J. Peter Lesley, LL. D., 1008 Clinton St., Philadelphia, Pa.; State Geologist.

Frank Leverett, B. S., Denmark, Iowa.; Assistant U. S. Geological Survey. August, 1890.

Waldemar Lindgren, U. S. Geological Survey, Washington, D. C. August, 1890.

Robert H. Loughridge, Ph. D., Berkeley, Cal.; Assistant Professor of Agricultural Chemistry in University of California. May, 1889.

Albert P. Low, B. S., Geological Survey Office, Ottawa, Canada; Geologist on Canadian Geological Survey. August, 1892.

Thomas H. Macbride, Iowa City, Iowa; Professor of Botany in the State University of Iowa. May, 1889.

Henry McCalley, A. M., C. E., University, Tuscaloosa county, Ala.; Assistant on Geological Survey of Alabama. May, 1889.

Richard G. McConnell, A. B., Geological Survey Office, Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. May, 1889.

James Rieman Macfarlane, A. B., Pittsburg, Pa. August, 1891.

* W J McGee, Washington, D. C.; Bureau of North American Ethnology.

William McInnes, A. B., Geological Survey Office, Ottawa, Canada; Geologist, Geological and Natural History Survey of Canada. May, 1889.

Peter McKellar, Fort William, Ontario, Canada. August, 1890.

Oliver Marcy, LL. D., Evanston, Cook Co., Ill.; Professor of Natural History in Northwestern University. May, 1889.

Othniel C. Marsh, Ph. D., LL. D., New Haven, Conn.; Professor of Paleontology in Yale University. May, 1889.

Vernon F. Marsters, A. B., Bloomington, Ind.; Associate Professor of Geology in Indiana State University. August, 1892.

Edward B. Mathews, Ph. D., Baltimore, Md.; Instructor in Petrography in Johns Hopkins University. August, 1895.

P. H. Mell, M. E., Ph. D., Auburn, Ala.; Professor of Geology and Natural History in the State Polytechnic Institute. December, 1888.

John C. Merriam, Ph. D., Berkeley, Cal.; Instructor in Paleontology in University of California. August, 1895.

*Frederick J. H. Merrill, Ph. D., State Museum, Albany, N. Y.; Assistant State Geologist and Assistant Director of State Museum.

George P. Merrill, M. S., U. S. National Museum, Washington, D. C.; Curator of Department of Lithology and Physical Geology. December, 1888.

James E. Mills, B. S., Quincy, Plumas Co., Cal., December, 1888.

Thomas F. Moses, M. D., Urbana, Ohio. May, 1889.

*Frank L. Nason, A. B., 5 Union St., New Brunswick, N. J.; Assistant on Geological Survey of New Jersey.

*Peter Neff, A. M., 361 Russell Ave., Cleveland, Ohio; Librarian, Western Reserve Historical Society.

Frederick H. Newell, B. S., U. S. Geological Survey, Washington, D. C. May, 1889.

William H. Niles, Ph. B., M. A., Cambridge, Mass. August, 1891.

William H. Norton, M. A., Mt. Vernon, Iowa; Professor of Geology in Cornell College. December, 1895.

Charles J. Norwood, Frankfort, Ky.; State Mine Inspector of Kentucky. August, 1894.

*Edward Orton, Ph. D., LL. D., Columbus, Ohio; State Geologist and Professor of Geology in the State University.

*Amos O. Osborn, Waterville, Oneida Co., N. Y.

Charles Palache, B. S., Mineralogical Laboratory, Harvard University, Cambridge, Mass. August, 1894.

*Horace B. Patton, Ph. D., Golden, Col.; Professor of Geology and Mineralogy in Colorado School of Mines.

Richard A. F. Penrose, Jr., Ph. D., 1331 Spruce St., Philadelphia, Pa. May, 1889.

Joseph H. Perry, 176 Highland St., Worcester, Mass. December, 1888.

*William H. Pettee, A. M., Ann Arbor, Mich.; Professor of Mineralogy, Economical Geology and Mining Engineering in Michigan University.

Louis V. Pirsson, Ph. B., New Haven, Conn.; Assistant Professor of Inorganic Geology, Sheffield Scientific School. August, 1894.

*Franklin Platt, 1617 Chestnut St., Philadelphia, Pa.

*Julius Pohlman, M. D., University of Buffalo, Buffalo, N. Y.

William B. Potter, A. M., E. M., St. Louis, Mo.; Professor of Mining and Metallurgy in Washington University. August, 1890.

*John W. Powell, Bureau of Ethnology, Washington, D. C.

*Charles S. Prosser, M. S., Schenectady, N. Y.; Professor of Geology in Union College.

*Raphael Pumpelly, U. S. Geological Survey, Newport, R. I.

Frederick L. Ransome, B. S., Berkeley, Cal. August, 1895.

Harry Fielding Reid, Ph. D., Johns Hopkins University, Baltimore, Md. December, 1892.

William North Rice, A. M., Ph. D., LL. D., Middletown, Conn.; Professor of Geology in Wesleyan University. August, 1890.

Heinrich Ries, Ph. B., Fellow in Mineralogy, Columbia College, New York city. December, 1893.

Charles W. Rolfe, M. S., Urbana, Champaign Co., Ill.; Professor of Geology in University of Illinois. May, 1889.

*Israel C. Russell, M. S., Ann Arbor, Mich.; Professor of Geology in University of Michigan.

*James M. Safford, M. D., LL. D., Nashville, Tenn.; State Geologist; Professor in Vanderbilt University.

Orestes H. St. John, Topeka, Kan. May, 1889.

*Rollin D. Salisbury, A. M., Chicago, Ill.; Professor of General and Geographic Geology in University of Chicago.

Frederick W. Sardeson, University of Minnesota, Minneapolis, Minn. December, 1892.

*Charles Schaeffer, M. D., 1309 Arch St., Philadelphia, Pa.

Charles Schuchert, Washington, D. C.; Assistant Curator in Paleontology, U. S. National Museum. August, 1895.

William B. Scott, M. A., Ph. D., 56 Bayard Ave., Princeton, N. J.; Blair Professor of Geology in College of New Jersey. August, 1892.

Henry M. Seely, M. D., Middlebury, Vt.; Professor of Geology in Middlebury College. May, 1889.

Alfred R. C. Selwyn, C. M. G., LL. D., Ottawa, Canada. December, 1889.

*Nathaniel S. Shaler, LL. D., Cambridge, Mass.; Professor of Geology in Harvard University.

Will H. Sherzer, M. S., Ypsilanti, Mich.; Professor in State Normal School. December, 1890.

*Frederick W. Simonds, Ph. D., Austin, Texas; Professor of Geology in University of Texas.

*Eugene A. Smith, Ph. D., University, Tuscaloosa Co., Ala.; State Geologist and Professor of Chemistry and Geology in University of Alabama.

James Perrin Smith, M. S., Ph. D., Palo Alto, California; Assistant Professor of Paleontology, Leland Stanford Jr. University. December, 1893.

*John C. Smock, Ph. D., Trenton, N. J.; State Geologist.

Charles H. Smyth, Jr., Ph. D., Clinton, N. Y.; Professor of Geology in Hamilton College. August, 1892.

Henry L. Smyth, A. B., Cambridge, Mass.; Instructor in Mining Geology in Harvard University. August, 1894.

*J. W. Spencer, A. M., Ph. D., 1320 Corcoran St., Washington, D. C.

Josiah E. Spurr, A. B., A. M., Gloucester, Mass. December, 1894.

Joseph Stanley-Brown, 1318 Massachusetts Ave., Washington, D. C. August, 1892.

Timothy William Stanton, B. S., U. S. Geological Survey, Washington, D. C.; Assistant Paleontologist U. S. Geological Survey. August, 1891.

*John J. Stevenson, Ph. D., LL. D., University of the City of New York; Professor of Geology in the University of the City of New York.

Joseph A. Taff, B. S., Washington, D. C.; Assistant Geologist U. S. Geological Survey. August, 1895.

Ralph S. Tarr, Cornell University, Ithaca, N. Y.; Assistant Professor of Geology. August, 1890.

Frank B. Taylor, Fort Wayne, Ind. December, 1895.

*Asa Scott Tiffany, 901 West Fifth St., Davenport, Iowa.

*James E. Todd, A. M., Vermillion, S. Dak.; Professor of Geology and Mineralogy in University of South Dakota.

*Henry W. Turner, B. S., U. S. Geological Survey, Washington, D. C.

Joseph B. Tyrrell, M. A., B. Sc., Geological Survey Office, Ottawa, Canada; Geologist on the Canadian Geological Survey. May, 1889.

*Edward O. Ulrich, A. M., Newport, Ky.; Paleontologist of the Geological Survey of Minnesota.

*Warren Upham, A. M., Librarian Minnesota Historical Society, St. Paul, Minn.

*Charles R. Van Hise, M. S., Madison, Wis.; Professor of Mineralogy and Petrography in Wisconsin University; Geologist U. S. Geological Survey.

*Anthony W. Vogdes, Alcatraz Island, San Francisco, Cal.; Captain Fifth Artillery, U. S. Army.

*Marshman E. Wadsworth, Ph. D., Houghton, Mich.; State Geologist; Director of Michigan Mining School.

*Charles D. Walcott, U. S. National Museum, Washington, D. C.; Director U. S. Geological Survey.

Walter H. Weed, M. E., U. S. Geological Survey, Washington, D. C. May, 1889.

Lewis G. Westgate, 1303 Chicago Ave., Evanston, Ill. August, 1894.

Thomas C. Weston, Ottawa, Canada. August, 1893.

David White, U. S. National Museum, Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey, Washington, D. C. May, 1889.

*Israel C. White, Ph. D., Morgantown, W. Va.

*Charles A. White, M. D., U. S. National Museum, Washington, D. C.; Paleontologist U. S. Geological Survey.

Joseph Frederick Whiteaves, Ottawa, Canada; Paleontologist and Assistant Director Geological Survey of Canada. December, 1892.

*Robert P. Whitfield, Ph. D., American Museum of Natural History, 77th St. and Eighth Ave., New York city; Curator of Geology and Paleontology.

*Edward H. Williams, Jr., A. C., E. M., 117 Church St., Bethlehem, Pa.; Professor of Mining Engineering and Geology in Lehigh University.

*Henry S. Williams, Ph. D., New Haven, Conn.; Professor of Geology and Paleontology in Yale University.

Bailey Willis, U. S. Geological Survey, Washington, D. C. December, 1889.

*Horace Vaughn Winchell, 1306 S. E. 7th St., Minneapolis, Minn.; Assistant on Geological Survey of Minnesota.

*Newton H. Winchell, A. M., Minneapolis, Minn.; State Geologist; Professor in University of Minnesota.

*Arthur Winslow, B. S., Roe Building, 5th and Pine streets, St. Louis, Mo.

John E. Wolff, Ph. D., Harvard University, Cambridge, Mass.; Assistant Professor in Petrography, Harvard University. December, 1889.

Robert Simpson Woodward, C. E., Columbia College, New York city; Professor of Mechanics in Columbia College. May, 1889.

Jay B. Woodworth, B. S., Cambridge, Mass.; Instructor in Harvard University. December, 1895.

Albert A. Wright, A. B., Ph. B., Oberlin, Ohio; Professor of Geology in Oberlin College. August, 1893.

*G. Frederick Wright, D. D., Oberlin, Ohio; Professor in Oberlin Theological Seminary.

Lorenzo G. Yates, M. D., Los Angeles, Cal. December, 1889.

William S. Yeates, A. B., A. M., Atlanta, Ga.; State Geologist of Georgia. August, 1894.

FELLOWS DECEASED

*Indicates Original Fellow (see article III of Constitution)

*Charles A. Ashburner, M. S., C. E. Died December 24, 1889.
Amos Bowman. Died June 18, 1894.
*J. H. Chapin, Ph. D. Died March 14, 1892.
George H. Cook, Ph. D., LL. D. Died September 22, 1889.
Antonio del Castillo. Died October 28, 1895.
*James D. Dana, LL. D. Died April 14, 1895.
*Albert E. Foote. Died October 10, 1895.
*Robert Hay. Died December 14, 1895.
David Honeyman, D. C. L. Died October 17, 1889.
Thomas Sterry Hunt, D. Sc., LL. D. Died February, 1892.
*Henry B. Nason, M. D., Ph. D., LL. D., Troy, N. Y. Died January 17, 1895.
*John S. Newberry, M. D., LL. D. Died December 7, 1892.
*Richard Owen, LL. D. Died March 24, 1890.
Charles Wachmuth. Died February 7, 1896.
*George H. Williams, Ph. D. Died July 12, 1894.
*J. Francis Williams, Ph. D. Died November 9, 1891.
*Alexander Winchell, LL. D. Died February 19, 1891.

Summary

Original Fellows	87
Elected Fellows	141
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ACCESSIONS TO LIBRARY FROM JANUARY, 1895, TO MARCH, 1896

BY H. L. FAIRCHILD, *Secretary and Acting Librarian*

Contents

(*A*) FROM SOCIETIES AND INSTITUTIONS RECEIVING THE BULLETIN AS DONATION ("EXCHANGES")*

(*a*) *AMERICA*

NEW YORK STATE MUSEUM, ALBANY

937–943. Annual Reports, Nos. 41 (1887)–47 (1893).

BOSTON SOCIETY OF NATURAL HISTORY, BOSTON

5. Proceedings, vol. xxvi, part 4, Nov., 1894–May, 1895, pp. 393–562.

CHICAGO ACADEMY OF SCIENCES, CHICAGO

833. Bulletin, vol. i, Nos. i–x, 1883–1886, pp. 1–118.
834. " " ii, Nos. i, ii, 1891–1895, pp. 1–189.
946. Thirty-eighth Annual Report, 1895, pp. 1–16.

FIELD COLUMBIAN MUSEUM, CHICAGO

1000. Publication 3, Geological Series, vol. i, No. 1, Aug., 1895.
1001. " 5, 7, Zoölogical Series, vol. i, No. 1, Oct.–Nov., 1895.
1002. " 6, Report Series, vol. i, No. 1, Oct., 1895.

CINCINNATI SOCIETY OF NATURAL HISTORY, CINCINNATI

836–852. Journal, vols. i–xvii, 1878–1894 (excepting pp. 71–160, vol. iii).

COLORADO SCIENTIFIC SOCIETY, DENVER

853. Proceedings, vol. iv, 1891–1893, pp. i–xxix + 1–456.
854. Nine separate papers, 1894–'95.
947. Two " " dates, Oct. 7 and Nov. 4, 1895.

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*This list includes only those "exchanges" from which some gift has been received during the year.

NOVA SCOTIAN INSTITUTE OF SCIENCE, HALIFAX

948. Proceedings and Transactions, vol. viii, part 4, 1895, pp. 381–470.

MUSEO DE LA PLATA, LA PLATA

855–860. Revista, Tomos i–vi, 1890–1895, royal 8vo.
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