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ON SOME INVERTEBRATE FOSSILS FROM THE LYKINS FORMATION OF EASTERN COLORADO

BY

George H. Girty

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ON SOME INVERTEBRATE FOSSILS FROM THE LYKINS FORMATION OF EASTERN COLORADO[1]

By George H. Girty

(*Read by title before the Academy, 5 February, 1912*)

The fossils which form the subject of the following account were collected by Mr. Roy M. Butters and kindly placed by him in my hands for study. They were obtained in the Lykins formation of Colorado and represent a horizon in the Paleozoic higher than any at which fossils have heretofore been found along the eastern flank of the Front Range.

A detailed account of the stratigraphic relations and correlation of the Lykins formation has been prepared and will shortly be published by Mr. Butters. To a manuscript of this report, which I have been permitted to read, I largely owe the following data which seemed essential to the understanding of this limited but interesting fauna.

The "Red Beds" of the Front Range in Colorado have been variously classified and named. Their nomenclature and synonymy is, therefore, rather complicated, but as a general statement, it may be said that the Wyoming formation of Emmons has been divided into three formations, of which the Lykins is the highest. Below the Lykins, there occurs a series of strata (the lower Wyoming) which are now known as the Fountain and Lyons formations, while above the Lykins is the Morrison formation. The Lykins, therefore, belongs in the upper "Red Beds" of this area. The Fountain has furnished more or less conclusive paleontologic evidence of Pennsylvanian, or at least of upper Carboniferous, age, while the Morrison has long been known to be Mesozoic. The Lykins formation, from which fossils have not hitherto been known, has usually been assigned to the Triassic, but the evidence herewith presented seems to show conclusively that the formation, or at all events that portion of it from which the fossils were obtained, is Paleozoic. Provisionally, I am assigning the Lykins fauna to the Permian, though more on account of its position at the top of the Paleozoic section than on account of any very close resemblance either to the Permian of Russia, the more or less doubtful Permian of our Western States or the Permian as distinguished from the Pennsylvanian of the Mississippi Valley. The only fauna in

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[1] Published by permission of the Director of the U. S. Geological Survey.

Colorado which conspicuously resembles the Lykins occurs in the Rico formation of the San Juan region, and the Lykins and Rico are tentatively placed in correlation, in spite of the fact that many of the Rico forms are as yet not known in the Lykins and some of the characteristic Lykins forms are not known in the Rico.

The character of the Lykins formation, as would naturally be supposed, changes from point to point. A well-exposed section at Heygood Canyon which is fairly representative consists, according to Mr. Butters, of sandstone and shale with some beds of sandy limestone. The sandstones are pink or red and mostly soft, while the shales are red. The thickness of the Lykins at this point is 816 feet.

A little south of Heygood Canyon on the north slope of Table Mountain were made three collections of fossils (lots 3264, 3265 and 3266). They occur about 300 feet above the base of the formation and about 25 feet above a 25-foot bed of gypsum. They contain the same species, viz: *Myalina perattenuata, Myalina wyomingensis, Alula squamulifera* and *Murchisonia buttersi.* The matrix is a compound of fine sand and clay with more or less lime, the color being a rather light brownish gray.

Another collection was made near Stout, Colorado, from a red calcareous sandstone (lot 3262). Only two species are present, *Myalina wyomingensis* and *M. perattenuata.* The horizon is about 30 feet above the "crossbedded sandstone" [2] in the basal member of a local group of calcareous strata 50 to 60 feet thick consisting of thin limestones, shales and sandstones.

The last collection (lot 3263) was made at Perry Park, one-fourth of a mile south of the lake, in a band about 6 inches thick near the base of the "crinkled sandstone." [3] The rock is whitish in color and very fine in texture, apparently a mixture of lime and clay and sand. In this collection, I identify *Myalina wyomingensis*, *Myalina perattenuata, Alula squamulifera, Alula gilberti?* and *Pleurophorus* sp.

Lot 3263 occurs at a higher horizon than 3262 and recalls, especially by the peculiar and characteristic species *Alula squamulifera,* the fauna of the northern group of collections (lots 3264, 3265, 3266), from which, however, it is separated geographically by a long distance.

The fauna of the Lykins formation is, so far as known, very limited, consisting of only six species, and in addition to describing the two species, which are new, it has seemed desirable to remark briefly upon the other forms.

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[2] Colorado Geol. Survey, First Report, pp. 168-9. 1909.

[3] U. S. Geol. Survey, Bull. 265, p. 25. 1905.

Alula gen. nov.

Shell soleniform, very transverse. Beak strongly anterior, but not terminal. Upper and lower margins contracting posteriorly. Posterior outline obliquely truncated. Umbonal ridge angular, with a second plication on the post-cardinal slope. Surface elegantly sculptured by fine radial costæ surmounted by fine, closely arranged scales or interrupted concentric lamellæ. Post-cardinal slope without radial costæ, but with similar squamose ornamentation. On the interior, the right valve has a single long, plate-like anterior tooth, a posterior tooth of similar character, with possibly a small rounded tooth at the umbo. Corresponding structures appear to be developed in the left valve. A large anterior scar is indicated.

Type, *Alula squamulifera*.

In a general way, these shells suggest a very transverse type of *Parallelodon,* and I believe that they belong to the same family, though clearly representing a distinct genus. In configuration, they differ from *Parallelodon* in contracting posteriorly instead of anteriorly; in not having the angular and projecting anterior extremity, and in possessing a second plication between the umbonal ridge and the cardinal border. Interiorly, they differ in having a single posterior tooth; in having a linear anterior tooth similar to the posterior one, and probably in lacking the flexuous dental arrangement at the umbones. A certain resemblance to some species of *Pleurophorus* exists in the angular umbonal ridge and the post-umbonal fold, but the *Pleurophori* are not radially striated, and, while they have a similar posterior tooth, the remainder of the dentition is quite different.

It is not certain that any American species other than the type can be referred to this genus, but, if so, they are probably to be found among the forms which I provisionally included under *Pleurophorella.* A resemblance to *Alula squamulifera,* more or less marked, is found in *P. geinitzi, P. gilberti, P. lanceolata* and *Allerisma* (*Pleurophorella?*) *reflexum.* Of these, the most similar is *P. gilberti.* Typical *Pleurophorella,* as exemplified by *P. papillosa,* is probably safely distinct, although its internal characters are as yet unknown, because of the deeply introverted lunule and the escutcheon, both characters apparently wanting to *Alula,* and because of the absence of radiating costæ in the sculpture, although a somewhat similar feature exists in the characteristic papillæ, which show a tendency to radial arrangement. There is, however, scarcely any comparison in this item of sculpture. As a provisional arrangement, I am removing to the present genus *A. gilberti, A. geinitzi* and *A.? lanceolata. Allerisma reflexum,* in spite of a general resemblance to this series of forms, probably has quite different, although indeterminate, relations, distinctly not with typical *Allerisma.* As a result of a better knowledge of *Allerisma costatum* and a renewed consideration of its characters, I believe that my original estimate of its relationship to *Pleurophorella papillosa* was erroneous. The strong concentric plications which stop abruptly at the umbonal ridge indicate a different type of shell. It is somewhat doubtful whether a papillose surface is a real character of *A. costata,* which is apparently a much flatter shell, with thin test and possibly different structure in the lunule and escutcheon. It clearly does not belong with *Alula,* however, but has all the superficial characters of typical *Sanguinolites.*

Alula squamulifera

Shell rather small, very transverse. Width about 3.5 times the greatest height. Greatest height near the anterior end at the umbo, which is situated about one-sixth of the entire width back from the anterior margin. Ventral border gently convex in the anterior half, nearly straight or faintly concave posteriorly. Dorsal outline gently concave or nearly straight, contracting posteriorly with the ventral. Posterior outline oblique and more or less sharply truncate. Anterior outline straight above, strongly rounding below. Convexity usually rather high, though variable, sometimes rather tumid in the umbonal region. Beaks large, prominent and incurved, situated relatively close to the anterior extremity. Umbonal ridge prominent, usually strongly angular toward the posterior end, more obscure in the umbonal region. The post-cardinal slope is divided by a second plication about intermediate between the umbonal ridge and the cardinal line, above which the narrow strip of shell is nearly horizontal. Surface marked by fine, radiating ribs which are confined to the portion of the shell below and in front of the umbonal ridge. This sculpture might better be described as made by narrow striæ, the elevations between which are covered with closely arranged, fine, flat scales, which recur at equal intervals on adjacent ribs and have also the appearance of interrupted concentric lamellæ. The ribs are more than radiating rows of scales, since the spaces between them are depressed. The scales are sometimes more or less curved with the convex side uppermost, especially at the anterior end, where they are replaced by two or more rows (the radiating arrangement often not being apparent) of minute spines or papillæ. Apparently, these spines become more or less compressed toward the middle of the shell and then coalesce at their edges. If they are not quite in alignment, the curved appearance noted above results. The post-cardinal slope, which, as already mentioned, lacks radiating ribs, is nevertheless marked by these flattened scales, which tend to be arranged in concentric rows without, however, becoming connected into continuous lamellæ. No radial arrangement is here apparent.

The internal structures are imperfectly known. The right valve bears two linear teeth, one before and one behind the beaks. The posterior tooth is long, about two-thirds the entire length back of the beaks. The anterior tooth is much shorter, about one-half the length of the anterior outline. Whether a small cardinal tooth was developed between these at the umbo is not clearly shown, but such a structure is indicated. In the left valve, there appear to be linear sockets corresponding to the teeth of the right. A large anterior scar is indicated.

Of described species, this appears most closely to resemble *A. gilberti*, though it is not certain that the two are congeneric. The chief difference of a possible generic character lies in the fact that White's figure appears to represent *A. gilberti* as having a well-marked escutcheon, a structure probably not present in *A. squamulifera*. Specifically, the latter appears to be a more slender form, more convex, and with a sharper umbonal ridge (these characters, however, may be enhanced by compression in the Colorado form). It is also distinctly, though finely, costate, although *A. gilberti* in fact is covered with granules arranged in rows, so as to resemble minute radiating liræ.

HORIZON AND LOCALITY: Lykins formation; Heygood Canyon (lots 3264, 3265, 3266) and Perry Park (lot 3263), Colorado.

Alula gilberti White?

Alula squamulifera is abundant in lot 3263, but specimens are in an unsatisfactory condition of preservation. Many of them show a lower convexity and less angular umbonal ridge than the types. One example is sufficiently shallow, broad and ill-defined as to umbonal ridge to resemble *Allerisma gilberti* rather closely. The sculpture is obscure but presents suggestions of radiating costæ or of rows of papillæ. The depressed specimens which are provisionally placed with *A. squamulifera* appear to show a gradation toward but not into the only one referred to White's species, and the facts which I have been able to observe leave me in doubt as to whether we have three species of not necessarily generically identical shells, or a fairly continuous series of mutations with *A. squamulifera* at one end and *A. gilberti* (or the form here identified as such) at the other.

HORIZON AND LOCALITY: Lykins formation; Perry Park, Colorado (lot 3263).

Myalina wyomingensis Lea

Myalinas are extremely abundant in four of the five collections examined, but most of the specimens are small. They vary in specific character. Some of the larger and more typical specimens agree in every determinable character with forms from the Rico formation of the San Juan region which I identified as *Myalina wyomingensis*.[4] The great majority are of much smaller size, more like the form from Ouray which I somewhat provisionally called *M. cuneiformis*.[5] They naturally have the anterior lobe less strongly developed than the larger or mature examples which accompany them. They seem as a rule to be less strongly

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[4] U. S. Geol. Survey, Prof. Paper 16, Plate VIII, Fig. 8. 1903.

[5] *Ibid.*, Plate VIII, Figs. 16 and 17.

oblique than the type specimens of *M. cuneiformis,* though some of them have the lobe scarcely more apparent. I am regarding part of these small specimens as being young examples of *M. wyomingensis,* and this may also be the true relationship of the Ouray specimens referred to *cuneiformis.* Typical *cuneiformis* should probably be kept distinct for the time being.

Horizon and locality: Lykins formation; Heygood Canyon (lots 3264, 3265 and 3266), Stout (lot 3262) and Perry Park (lot 3263), Colorado.

Myalina perattenuata Meek and Hayden

The Myalinas of the Lykins formation in addition to showing variation in the amplitude of the posterior wing vary conspicuously in the development of the anterior lobe. Some specimens have scarcely any perceptible development of this feature. These, although they are not sharply distinguished from the typical *M. wyomingensis,* I am separating as a different species under the title *M. perattenuata.* A similar phenomenon was observed in the Myalinas of the Rico formation of the San Juan region, and a similar course was pursued in regard to them. These Lykins specimens, however, are for the most part much smaller than those from the Rico formation and in this character approximate *M. cuneiformis,* but most of them are distinctly less oblique. A not very considerable breakage along the hinge line of these small shells however, or a concealment of the true outline in that region, makes an appreciable difference in their apparent obliquity.

Horizon and locality: Lykins formation; Heygood Canyon (lots 3264, 3265 and 3266), Stout (lot 3262) and Perry Park (lot 3263), Colorado.

Pleurophorus sp.

A very imperfect internal mold showing best the impression of the hinge structures in the umbonal region, where they possess the characteristic dental arrangement of *Pleurophorus.* For the rest, there is indicated a transverse, oblong shell of medium size with rather strongly projecting anterior end.

Horizon and locality: Lykins formation; Perry Park, Colorado (lot 3263).

Murchisonia buttersi sp. nov.

Shell of medium size, slender, with high, many-whorled spire. Length of the type specimen as restored about 25 mm. Diameter of final whorl 11 mm. Number of volutions 10. Volutions angular with a thick. prominent carina situated considerably below the middle, the height of the upper zone being to that of the lower about as 2 to 1. Upper and lower zones more or less planate and standing at approximately a right angle to one another. The lower is gently concave, more so than the upper, although the upper spoons outward as it approaches the carina. Suture deeply depressed.

The most conspicuous superficial feature consists of narrow angular costæ, leaving between them broad shallow interspaces, which cross the upper portion of the volutions transversely or in a direction longitudinal to the shell as a whole. They are straight, but are slightly oblique, retrally directed from above downward. These plications are perhaps restricted to the three or four older volutions, and there is some irregularity in their arrangement. They die down before reaching the carina. In addition, the whole surface of the upper zone is marked by microscopic transverse and revolving liræ producing a more or less cancellated effect. The revolving liræ are rounded, closely arranged and prone to be wavy. The transverse liræ are finer, sharper and more irregular, more of the nature of incremental lamellæ, and the costæ may perhaps be looked on as fascicles of these markings. The lower zone of the volution is marked similarly to the upper, but the angular costæ are less strong. They have a slight forward obliquity from the carina. There appear to be two, possibly more, strong rounded revolving liræ on the final volution at a point, as it would appear, about half-way down from the carina, and the volutions so embrace as to leave about two of these liræ visible above the deeply sunk suture. The final volution is not well shown by the specimens examined, so that the sculpture below these two liræ, the relative distance at which they occur below the carina, the shape of the aperture, etc., are not known. The carina is the site of the slit band. The band is occupied by two rather coarse, rounded liræ, separated by a narrow stria and appears to be defined by two delicate lamellose lines, one above and one below, bounded on the median side by slight striæ. The two revolving liræ which occupy the whole of the band and are more projecting than the edges are rendered nodose by the costæ described as crossing the upper and lower surfaces of the volution. That is, the swellings occur where the costæ would cross them, but the costæ are evanescent on the upper surface near the band, and the nodes are much more prominent than the costæ and much more elongated spirally.

In its specific relations, this shell is most nearly related to *Murchisonia lasallensis* and *M. terebra*. It differs from both in the presence of transverse plications. From *terebra*, which seems to be more nearly related than the other, it apparently differs also in having the carina containing two crenulated liræ instead of one, in having two revolving liræ just above the suture and in other details of sculpture.

Generically, this shell can hardly be classed with typical *Murchisonia*, though it belongs to a group frequently cited under that genus. In some important respects, it is comparable with such representatives of the genus *Worthenia* as *W. tabulata*. This is especially true of the structure of the slit band, which seems to be identical in both. Given a much higher spire and more gradually enlarging volutions, with some modifications in the modeling of the whorls, especially the lower part, it is easy to conceive how such a configuration as that of *M. buttersi* might be evolved from that of *Worthenia tabulata.* The sculpture also appears to be of the same general character, the most essential difference being the development of transverse costæ and of revolving liræ more prominent than the rest on the lower half of the inferior zone. Some important characters of *M. buttersi* are still unknown, but if these show no additional differences, it may prove to be a rather extreme form of *Worthenia.*

Horizon and locality: Lykins formation; Heygood Canyon, Colorado (lots 3264 and 3266).

PLATE I

LYKINS FOSSILS

Myalina perattenuata (p. 6)

FIG. 1. A large right valve referred to this species.
2. A left valve of more nearly the average size.
Lykins formation, Heygood Canyon, Colorado (lot 3266).

Myalina wyomingensis (p. 5)

3. A large left valve.
Lykins formation, Heygood Canyon, Colorado (lot 3265).

Alula squamulifera (p. 4)

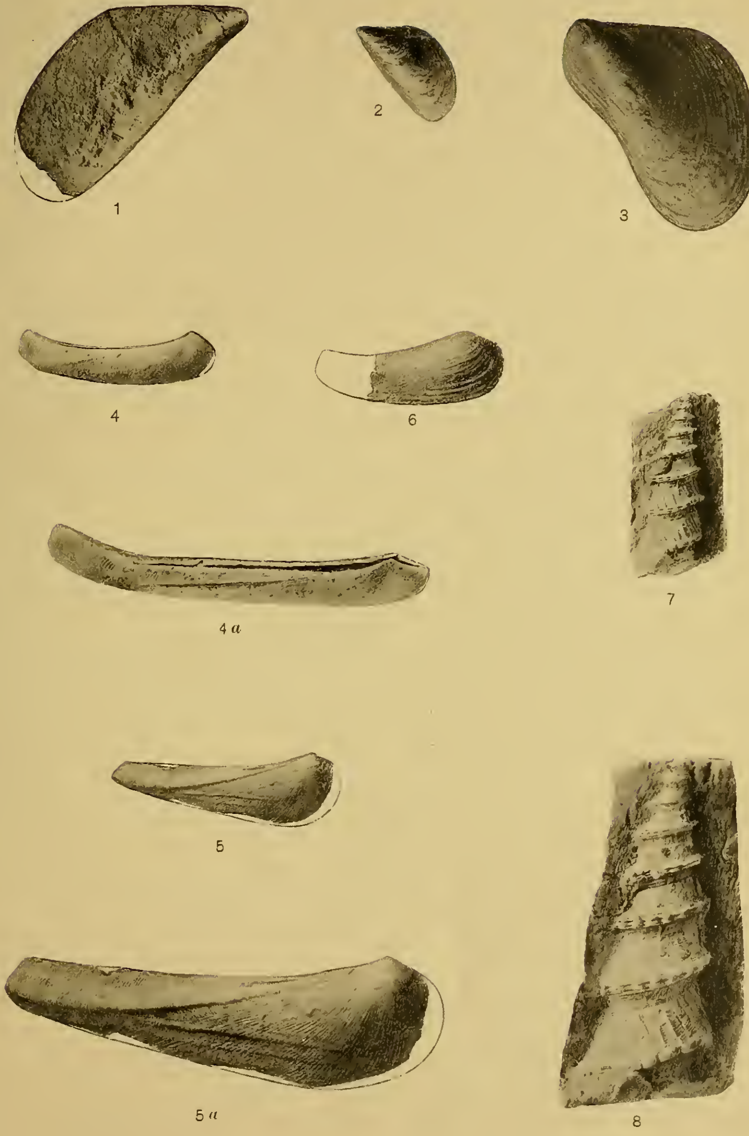
4. Side view of an internal mold of a right valve.
4*a*. A view obliquely down on the cardinal margin of the same specimen, showing the impression left by the linear anterior and posterior teeth, x 2.
5. Squeeze of a right valve showing the surface characters.
5*a*. Same, x 2. Even with this magnification, the fine squamose character of the costæ cannot be shown.
Lykins formation, Heygood Canyon, Colorado (lot 3266).

Alula gilberti ? (p. 5)

6. Side view of a doubtfully identified right valve.
Lykins formation, Perry Park, Colorado (lot 3263).

Murchisonia buttersi (p. 6)

7. Side view of a squeeze made from the type specimen.
8. Another squeeze made from the same specimen, x 2.
Lykins formation, Heygood Canyon, Colorado (lot 3264).



FOSSILS FROM THE LYKINS FORMATION

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SOME FACTORS OF GEOGRAPHICAL DISTRIBUTION IN SOUTH AMERICA

BY

JOHN D. HASEMAN

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SOME FACTORS OF GEOGRAPHICAL DISTRIBUTION IN SOUTH AMERICA

BY JOHN D. HASEMAN

[Presented in abstract before the Academy, 12 February, 1912]

CONTENTS

INTRODUCTION

South America has not lacked the labor of scientific explorers; none the less one may safely state that fully one half its surface is still practically unknown. This is due to the fact that its investigators have been relatively few, but even had there been many scores of them they could not adequately have explored such an expanse of land beset with countless natural obstacles.

When attention is drawn to the fact that Brazil, which is one of the best known South American republics, is larger than the United States itself, it becomes evident that the few dozens of explorers within recent times could not have examined more than the regions accessible from the coast, from the few railroads and from the larger rivers.

Pioneer work in the interior of tropical America must often depend on meager and often incorrect information. This is reflected even in the maps of South America, for in every one some of the material has been taken from untrustworthy local sources.

It was on account of this lack of decisive knowledge concerning certain parts of South America, even in the best books of reference, that the director of the Carnegie Museum dispatched the writer, in 1907, in charge of the Carnegie Museum Expedition to Brazil. One of the primary objects of this journey was to study the distribution of the fishes; but kindred problems were not to be neglected, and data were collected on every hand and over a far greater territory, partially known or quite unexplored, than had been originally suggested. This was found possible because the writer was fortunate in maintaining excellent health throughout his journeys. (See Plate II for routes followed.)

For this excellent opportunity to explore many regions of South America, I am deeply indebted to the founder and the trustees and to Dr. W. J. Holland, the director of the Carnegie Museum.

Acknowledgment should be made to Dr. O. A. Derby, the director of the Brazilian Geological Survey, for many favors and much useful information in furtherance of my work; to Prof. J. C. Branner and to Mr. R. Crandall, both of whom assisted me notably on my first trip to Bahia. Mr. Crandall examined my notes and map of the Cretaceous of northern Brazil. This enabled me to add valuable corrections. He has also kindly submitted me some notes on the trend lines of northeastern Brazil. Dr. Schuchert has put me into his debt for many invaluable suggestions, and so too has Dr. David White for corrections and suggestions in the discussion of the Gondwana flora.

My thanks are also due to the directors and staffs of the museums at

MAP OF PART OF SOUTH AMERICA

Showing journey made by J. D. Haseman under the auspices of the Carnegie Museum, 1907 to 1910, in Brazil, Uruguay, Argentina, Paraguay and Bolivia

Rio de Janeiro, São Paulo, Para, Montevideo and Buenos Aires, and among my other South American friends, to Ricardo Krone of Iguape, John Gordon, Alipio Miranda Ribeiro and Carlos Moreira of Rio de Janeiro, Dr. Jappa Assú of Bahia, Rudolfo von Ihering of São Paulo, Dr. Frank Davis and Feliciano Simon of Corumba and Dr. Snetlager of Para.

Among my preceptors, I record gratefully my indebtedness to Dr. Eigenmann, with whom I carried on my special studies in the University of Indiana; to Dr. A. E. Ortmann while I was in Pittsburgh, and to Drs. Dean, Grabau, Gregory and Hussakof while at Columbia, where a scholarship and the income of the Dyckman Fund for 1910 were generously granted me.[1]

The living and extinct fauna and flora of South America possess in certain cases, at least, a close genetic relationship with that of the southern portion of the eastern hemisphere. This remarkable fact has led to a prevailing view that South America was once connected with some point of the eastern hemisphere. This view assumes that the closely related fauna and flora are descended from common ancestors which existed in the old land mass or continent to which the name Gondwana has been applied.

In this thesis, it will be my effort to show that at least certain, if not all, elements in the fauna and flora of South America have evolved from forms which have from time to time been introduced from the northern hemisphere. In this view, I have brought together not only materials from references and from the laboratory but also data obtained during two and one half years of active field work. The amount of this material altogether will be sufficient, I think, to demonstrate that South America was never connected with the eastern hemisphere by a hypothetical southern and sunken mass of land.

In the preparation of my paper, I have been obliged to omit numerous data and assorted faunal lists whose bearing has been more or less direct upon the present theme—in the latter cases since I am convinced that the lists do not explain distribution unless accompanied by detailed observations upon the geology and the environmental conditions of the country considered. Hence I have been led to divide my thesis into two parts. In the first of these, we picture the past and present environments in which the fossil and existing animals lived. In the second, we deal with the changes through which these animals and their ancestral stocks have undergone after arriving in these environments.

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[1] The geographical names are spelled as they are in their respective countries. I have also used the old way of spelling such words as "Silurian" instead of "Siluric." I have also omitted marks of accentuation and other similar marks.

It is in the first part of this thesis that my effort will be to demonstrate on geological grounds that South America has not been connected with the eastern hemisphere. In this connection, I have also been able to map for the first time the outline of the Plano Alto (the highlands of South America) which was deposited by the wind and rivers in a dry land and fresh-water basin which I am calling the Permian Inland Basin. This highland, I propose to show, was of the utmost continental importance, from its dip, its lack of Mesozoic and Tertiary marine deposits and the direction of the trend lines, taken in connection with the Tertiary rise of the Andes; in fact, upon this I shall base my doctrine that the Amazon is a reversed river whose headwaters originally flowed into what I have designated the East Andean Sea.

This outlining of the Plano Alto is of prime importance, not only because it has given me the key to the correct explanation of the distribution of the aquatic life, but also because it shows that South America has not been cut into islands by east and west invasions of the sea as has been proposed by some of the exponents of the Archhelenis theory of von Ihering.

In other topographical matters which are of importance from the zoögeographical viewpoint, I will also show that the Paraguay River is not connected with the Guapore, as has been so often erroneously stated, and that Rio São Francisco is connected with Rio Tocantins. I will note additional cases of stream piracy and will show that these taken in connection with waterfalls, swamps and certain environmental conditions will aid us in interpreting with a certain degree of accuracy questions in the distribution of the South American fishes.

In the last part of this thesis, an attempt will be made to demonstrate that the fauna of South America has been evolved from the forms which originally lived in North America. In arriving at this conclusion, I have not entirely limited my studies to the fishes, but I have considered carefully the voluminous data derived from other groups of living and extinct animals and plants which have been used to establish connections between South America and the eastern hemisphere. I have considered all of these data, because the facts derived from the distribution of any one group of plants or animals are not sufficient alone to warrant an interpretation which involves profound modifications of the earth's surface as maintained by many authors.

In the matter of the distribution of fishes, as bearing upon the greater problem, my effort will be to show

1. That the present distribution of fishes gives no clue to the point of origin of the families, but it does for some of the genera and many species.
2. The point of family origin can only be determined after the living

and extinct forms have been carefully compared and a sharp distinction is made between paleotelic (old or phylogenetic) and cenotelic (recent, adaptive or physiological) characters. It is necessary to draw this distinction, because only paleotelic characters have been widely distributed.

3. That a fresh-water connection or its absence will not alone explain the present distribution of the fishes. Hence, the most important factor of living fish distribution is not land and water connections, *i. e.*, barriers, isolation, intermingling, etc., but it is the organic complex of the ancestral stock and the effects of different environments on this stock.[2]

4. That much of the similarity and some of the identity of certain species of the fishes of Rio Paraguay and Rio Amazonas are due to similar and identical evolution of the highland ancestral stock after arriving in similar environments, *e. g.*, as produced by the erosion of the highlands.

5. That the existing highland genera, small in size, are the more generalized types from which the bulk of South American fishes has evolved.

6. That the South American fishes have evolved from primitive forms which originally lived in North America.

The above statements do not in the main agree with the views expressed by previous zoögeographers. This difference of opinion is largely due to the fact that these investigators work from the static viewpoint of animal geography and have therefore only considered in some cases the "disconnected graveyard material," *i. e.*, a few isolated spots where the fauna died out; and in other cases the "hot-bed material," *i. e.*, the end result of the greatest cenogenic evolution. For this reason, their static faunal lists do not correctly determine the point of origin of families and orders. As a result of their conception of animal geography, some of these writers have maintained invasions of the sea and land-bridges for which there is no evidence. They have also brought to the support of their views some unnatural environments and unwarranted views of the geology and the topography of South America.

Another source of error in former interpretations is, I believe, the ignoring of the possibility of similar evolution of the identical ancestral stock in remote but similar environments. The necessity for the recognition of such evolution is due to the fact that in the same river basin there often exist (two or three) distinct faunal regions, one of which may show close affinity with another distinctly separated basin, while another river system, although connected (with the latter), may yet retain quite distinct faunas.

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[2] The idea that isolation alone produces new species implies the principle of selection, which is still of doubtful value. If it is not selection, then it must be in some way the direct or indirect (also debatable) influence of the environment on the germplasm or else it is orthogenesis.

My studies on the distribution of South American animals have also led me to place more emphasis on negative evidence than is usually granted by most writers. This difference of view is primarily due to the fact that a specialist in any one group of animals places too much weight on his positive evidence. Such emphasis at first sight appears to be absolutely correct, but on closer analysis it is usually contradicted by positive evidence from other groups of animals. For example, one author working on crustacea and mollusca finds that the alleged connection between South America and Africa had already disappeared in the early Cretaceous. If, however, we consider other groups, we find evidence which does not confirm this view. Thus, the affinity existing between the South American and African characinid and cichlid fishes is as close as that of the mollusca, yet there is no evidence that either of these families of fishes existed during the early Cretaceous.

In my conclusions, therefore, I have been led to balance the positive and negative evidence in the cases of many different groups. This balancing has been attempted not only by considering long lists of species, but by taking into due account the influence of various environments on the ancestral stocks (whose points of origin are usually unknown).

In fact, we should not, in such considerations, lose sight of the fact that our knowledge of the existing species of any group of South American and African animals is still very imperfect. Many species are still to be caught, many are exact synonyms and many are without doubt local somatic changes which are not always inherited. Therefore any positive evidence derived from such lists is, in my opinion, entirely inadequate to warrant the reconstruction of the earth's surface, unless supported by strong geological evidence. This is all the more true when there are other means of distribution which do not involve great topographical changes.

In point of fact, the inadequacy of the existing data is at once reflected by the number of alleged land-bridges and seas required during various past geological epochs. Each writer has constructed his new set of barriers, seas and land-bridges in his effort to explain the distribution of the fauna or flora in which he is recognized as an authority.

Notwithstanding the diversity of views concerning the time of existence and the location of the alleged land-bridges to the South American continent, we may roughly consider them under the following two groups:

1. The Gondwana Land of Suess and others—a late paleozoic continent traversing the greater part of the southern hemisphere and connecting India, Australia, South Africa and South America. The last remains of this old land-mass connecting Africa and South America have

been designated Archhelenis by von Ihering. Antarctica, another portion of Gondwana, is the name generally applied to the south polar continent which is believed by some to have been connected with South America and Australia and perhaps with Africa.

2. The persistence of the continental shelves and the great ocean basins. This view precludes the existence of former connections between South America and the eastern hemisphere, but admits the North American connections with Eurasia.

These two views involve not only the distribution of plants and animals but the geology of the entire earth. They are not new, dating back in fact nearly to the time (1857) when Sclater first placed geographical distribution in tangible form. In his scheme of distribution, the world was considered in six faunal regions, a scheme in which South America formed a major part of the neotropical realm.

In 1876, Wallace published two comprehensive volumes on the geographical distribution of animals. In these two most excellent volumes, the genus was used more than the species as a means of comparing faunal regions, and it appears that such a comparison is more luminous than one based on the species, for it is found that the generic characters are usually more nearly paleotelic than the specific ones; moreover, the list of species is the less accurate, since a far greater number of species than genera are still undescribed. The extensive data given in these two volumes indicate that the bulk of the ancestral land animals originated in the northern hemisphere. It is worthy of note that the views expressed by Wallace and some of the other earlier writers were far more conservative than those of more recent date.

It was during the interval from 1876 to 1890 that zoölogical, paleontological and geological data accumulated rapidly and yielded, especially, the excellent summation of the geology of the face of the earth by Suess and his views of the Gondwana Land (earlier suggested on purely paleontological grounds by Neumayer), and his considerations appear to have paved the way for von Ihering's Archhelenis theory which has more or less dominated most of the later studies on the zoögeography of South America.

Von Ihering has made, from time to time, slight changes in his theory, in order to meet the demands of more recent investigations. In 1907, he reconstructed the surface of the earth according to the views which he obtained from a detailed study of the mollusca. At the time, he maintained that, previous to and during a part of the Tertiary epoch, Brazil (Archibrazil or Archamazonia) was connected by Archhelenis with Africa and by Archiplata with Archinotis (Antarctic continent), which was also continuous with Australia. The sea traversed northern Brazil and separated the Guiana highlands plus the West Indies (Archiguiana) from the rest of South America, but it was connected with both Asia and Europe. Africa was not connected with Asia at that epoch. In 1911, he had made many changes in his views.

On the other hand, after a long detailed study of both the mollusca and crustacea, Ortmann has also maintained that an Archhelenis existed, but he differs with von Ihering both in regard to its location and the time of its disappearance. He believes that Archhelenis had already disappeared before the beginning of the Tertiary (perhaps the early Cretaceous) and that it connected Guiana and Africa.

Eigenmann (1909) has tested the Archhelenis theory with the distribution of the South American fishes and has found no objections to it. In fact, he states that the theory is quite useful in explaining the distribution of certain families of fishes, especially the Characinidæ and the Cichlidæ.

D. White (1907) in an excellent paper on the *Gangamopteris* flora (Gondwana flora) of Brazil does not, however, favor the Archhelenis land-bridge; he believes that an ancient connection (Permian) very probably existed between South America, the Antarctic continent and Australia or Africa.

In Part V of Volume III of the Princeton Patagonia reports, Pilsbry has summed up the distribution of non-marine mollusca of South America. His figure, page 632, indicates a former connection between the region of Pernambuco, Brazil and South Africa. He is inclined to believe that this connection disappeared by the end of the Cretaceous. He also admits the probability of a connection by way of the Antarctic islands with Australia, but he does not believe in a former isolation of the Guiana highlands from those of Brazil.

Schuchert (1911) also believes that the distribution of the brachiopoda shows clearly not only the former existence of an equatorial Gondwana across the Atlantic, but as well that its vanished Atlantic bridge still controls the distribution of living forms. He is of the opinion that Gondwana probably existed until middle Eocene times.

In the Age of Mammals (1910), Osborn re-states the widely accepted belief in an Antarctic connection between South America and the Australian realm, but he rejects a Tertiary Archhelenis. He thinks that this connection is necessary in order to explain the great similarity which exists between some of the fossil marsupials of Patagonia and the marsupials of the Australian realm. He also states that Matthew has rejected both the Archhelenis and the Antarctica connections and now maintains a northern origin of the southern fauna.

ARCHEAN AND OTHER PRE-CAMBRIAN AREAS OF SOUTH AMERICA

The solid black represents the Archean; the horizontally lined area represents the basal highland formation, which is generally considered to be pre-Cambrian and which is covered by alluvial deposits along the Amazon (dotted area).

The view held by Dr. Matthew and the writer (who have independently and from different standpoints arrived at several identical and fundamental conclusions concerning the distribution of South American animals) in a general way was put forth in 1886 by Haacke as the North Polar theory of the origin of land animals.[3]

PART I. GEOLOGY AND TOPOGRAPHY OF SOUTH AMERICA[4]

DISTRIBUTION OF GEOLOGICAL HORIZONS

It has been extremely difficult to map even the larger divisions of the geological ages found in South America, since the exact age and extent of many of the known formations have never been satisfactorily determined.

Archean

Archean rocks, as shown in a general way in Plate III, extend in a narrow belt, more or less broken, from Tierra del Fuego to the Isthmus of Panama. A great depression east of the Bay of Arica lies between the coastal Archean rocks of Chili and the inland Archean rocks of the northern Andean region. Another great belt of Archean rocks extends from Uruguay into the Serra do Mar and its various northern spurs of eastern Brazil. Archean rocks have also been encountered in isolated places of Patagonia, and a belt more or less broken extends from near Bahia Blanca through the Cordova Mountains into southern Bolivia. Finally, rocks of similar age have been encountered in northern Colombia, parts of Venezuela and Guiana.

The exact age of the crystalline schists, gneisses, granites, etc., which underlie the Plano Alto has never been satisfactorily determined, but they are usually considered pre-Cambrian or Archean on account of the entire absence of fossils. The lined portion of Plate III indicates the extent of these rocks.

Lisboa, one of the most competent Brazilian geologists, has reported crystalline rocks of pre-Cambrian (?) from near Miranda, Matto Grosso and in the basins of Rio Apa and Rio Aquidauana. The writer observed the basal highland rocks on the Bolivian side of Rio Guapore below the mouth of Rio Verde and on the Brazilian side of the Guapore at the

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[3] The bibliography gives a list of the publications which have been extremely useful to me, and I take the opportunity here to acknowledge my indebtedness to the authors. Few references have been given in the pages of this thesis, because it has been deemed advisable to omit them for the sake of clearness and brevity. Therefore some common information has been freely used.

[4] In the preparation of this part of the thesis, the writings of Derby, Branner, Suess, Eschwege, Hartt, Hatcher, Steinmann, Phillipi, Stelzner, Hauthal, Katzer, Crandall and numerous other authors given in the bibliography have been indispensable.

waterfalls of Forto de Principe da Beira. They were also seen along Rio Mamoré above Guaja Mirim, where the Serra de Pacas Novas approaches the river. Evans has reported gneisses, etc., from the Rio Beni and the Madeira falls. Katzer has maintained that this same basal highland formation extends under the deep alluvial deposits of the lower Amazon Valley. As a result of the writer's own observations, he is convinced that this is in the main the correct view. Hence this basal highland formation is very large, perhaps larger than indicated on Plate III.[5] The extent and form of these ancient rocks have given South America its present shape from the very beginning.

Silurian [6]

Silurian fossils have been reported from Rios Curua, Maecurú and Trombetas, which are affluents from the north side of the lower Amazon River; from Bom Jesus da Lapa, of Bahia; from some of the promontories of Venezuela; from the eastern chains of the mountains near the headwaters of Rio Bermejo, Argentina; west of San Juan along the eastern base of the Andes of northwestern Argentina; from Sierras de Famatina and La Rioja; from the mountains on either side of Sierra de Aconquija; from Sierra Aguilar, and from Cuzco, in southern Peru, extending past Illampu and Illimani through western Bolivia toward the Argentine chains of mountains. (?) Silurian (*Arthrophycus harlani*) was reported from Sierra de la Tandil.

The locations of these formations are shown on Plate IV, except that no distinction has been made for Ordovician because of the lack of data.

Devonian

Devonian fossils have been reported from Alameirim to Rio Uatuma at Erere, Rio Maecurú south of Larangal on the south side of Rio Amazonas; from Lagoinha near Cuyaba; from a belt extending from the State of São Paulo into the State of Parana at Ponto Grosso, at Jaguarahyva and in the Ivahy basin; in southern Peru and about Lake Titicaca, and in the Andes of Chili. Doubtfully from the northern part of Sierra Tandil. The locations of these formations are shown on Plate V.

Carboniferous

Carboniferous fossils have been reported from Rios Trombetas, Curua, Maecurú, Uatuma to Janary near Prainha and at Alemquer on the north

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[5] It must be granted that the regions supposed to yield exposures of Archean rocks may with more careful study be materially diminished, as has been the case in North America and Europe. If these rocks mapped as Archean are all older than the Carboniferous formations, then the ensuing views are not in the least affected.

[6] The Cambrian has not been mapped because of the lack of data. Deposits of this age have only been reported from a few places, as northern Argentina by Keyser, etc.

KNOWN MARINE DEPOSITS OF SILURIAN AGE IN SOUTH AMERICA

KNOWN MARINE DEPOSITS OF DEVONIAN AGE IN SOUTH AMERICA

KNOWN MARINE DEPOSITS OF CARBONIFEROUS AGE IN SOUTH AMERICA

KNOWN MARINE DEPOSITS OF PERMIAN AGE IN SOUTH AMERICA

KNOWN MARINE DEPOSITS OF TRIASSIC AND JURASSIC AGE IN SOUTH AMERICA

side of Rio Amazonas and along Rio Tapajos from Itaituba to Aveiro and west to Maueassu at Fructal and Rio Pedra do Barco on the south side of Rio Amazonas; from the Cordillera Oriental of Peru; from Lake Titicaca near Yampopata and extending south towards Cochabamba at Arque, Bolivia; Santa Cruz, Bolivia, and in the Chapoa Valley at la Ligua, Chili. The locations of these formations are shown on Plate VI.

Permian

Permian fossils have been reported from the State of São Paulo, Brazil, and this same belt extends south through Parana and Rio Grande do Sul and ends in Uruguay. Permian fossils are also known from a few isolated places in the Andes. The location of these formations is shown on Plate VII.

Triassic and Jurassic

The Triassic and Jurassic periods are unknown in Brazil. Triassic and Jurassic fossils have been reported from northern Colombia and Venezuela; from Puerto Puruay and Rio Maranhão of Rio Amazonas, and are widely spread in the Andes of Peru and Chili at Passo de los Patos, Coquimbo, Copiapo and elsewhere, where they are mixed with fresh-water deposits. The locations of these formations are shown on Plate VIII.

Cretaceous

Cretaceous fossils have been encountered in a narrow belt along the Brazilian coast from Ilhéos, south of Bahia, to Pirabas, near the mouth of Rio Amazonas. This coastal belt is never more than about 100 feet above the sea level, and its fossils also show that it must not be confused with the inland Cretaceous of northern Brazil which extends north from the State of Bahia across Rio São Francisco at Jatoba and widens out in the states of Piauhy and Ceara. This belt is often 1000 or more feet above the sea level. If the writer is correct in considering a formation (in which he found no fossils, but near where at Curimata fossil fishes, (?) *Diplomystus,* are said to exist) near Lagoa da Paranagua in the State of Piauhy as Cretaceous, then this belt will with all probability later be found to extend as far south as Serra da Tabatinga, but it does not extend into the Jalapão region of northern Goyaz.

The extreme northwestern extension of this Cretaceous is unknown, and consequently it offers alluring opportunities for future study,[7] be-

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[7] This belt may extend northwest into the State of Pará and as far west as the lower Tocantins basin. Mr. Roderic Crandall of the Brazilian Geological Survey has done the most field work on this inland Cretaceous belt, and his views agree in the main with those of the writer.

cause it will extend the limits of the Cretaceous deposits over a vast portion of northeastern Brazil.

Cretaceous deposits have been reported from Bahia, Espirito Santo, Aracajú, Alagoas, Maria Farinha, Jatoba, Riacho Doce, Serra de Araripe and Pirabas in Brazil; from the base of the mountains of Guiana; from Bogota and the region of Lake Maracaibo; from Sierra de Merida of Colombia and Venezuela; from Cordillera Nevada and from both sides of the Andes in the region of Alto Rio Maranhão; from Rio Acre (*Mosasaurus*); from Caracoles, Bolivia; from near Lima, Peru; Cochiyacu west of Rio Huallaga and north to Celendin; from near Guayaquil; from Tingo and south along both sides of the Andes toward Chili at Tomé, etc.; from Laguna Argentina to Tierra del Fuego; from Rio de los Patos west of San Juan, Argentina; from Colchagua, Coquimbo and Copiapo in Chili; from Sierra de Zenta east of San Juan, and perhaps from Gran Chaco toward the mountains about the headwaters of Rio Bermejo and Pilcomayo, but I am inclined to believe that these deposits are fresh water, as the most common form, *Melania*, is not typically marine. At any rate, this region needs some more careful study. The locations of these formations are shown on Plate IX.

Tertiary

Professor Branner is inclined to consider some of the marine formations of northeastern Brazil Eocene. This view has been recently corroborated by President Jordan's studies on the fossil fishes from Riacho Doce, but neither of these authors has entirely excluded the possibility of these formations being upper Cretaceous.

As far as the writer has been able to ascertain, from a first-hand knowledge of the region in question as well as from that of Crandall and also from a consideration of President Jordan's paper on the fossil fishes of the Serra de Araripe, it does not appear that any decisive evidence exists which establishes any marine Tertiary in northeastern Brazil. Fossil diplomystid fishes, the subject of President Jordan's paper, are known not only from the Cretaceous of Brazil, but also from the Cretaceous of other Continents. The fact that most of the diplomystids are found later than the Cretaceous epoch is no evidence that those of Serra de Araripe are Eocene. Furthermore, the peculiarities of the diplomystids of the Serra de Araripe will, with all probability, be found in various other localities of this region, when more exploration is completed.

For several reasons, therefore, I have mapped the outline of the Cretaceous belt on the map of the Tertiary epoch with a mark of interro-

KNOWN MARINE DEPOSITS OF CRETACEOUS AGE IN SOUTH AMERICA

KNOWN MARINE DEPOSITS OF TERTIARY AGE IN SOUTH AMERICA

gation, for later work may establish Tertiary deposits in at least part of this region, especially if we accept Professor Branner's view of its stratigraphy.[8]

Marine Tertiary fossils have been reported from Entre Rios, the Pampas and part of the Gran Chaco of Argentina; from the eastern base of the Andes, extending into the plains of Patagonia and as far south as Tierra del Fuego; from narrow belts along the coast of Peru and Chili; from the lower Orinoco valley; from Pebas, Peru, down Rio Solomoes as far as São Paulo de Olivenca, and from Canama on Rio Javary and probably from the region of Rio Acre, Brazil, and Santa Maria, Catamarca, west of Jejuhy in northern Argentina. The locations of these formations are shown on Plate X.[9]

TREND LINES

The trend lines of South America are about parallel to the coast, excepting in the region of Pernambuco and Ceara, Brazil. In this region, they appear to be fan-shaped. In regard to this most interesting region, I can do no better than quote a letter from Mr. R. Crandall, of the Brazilian Geological Survey, who has explored this region during the past four years:

"The general trend lines through all of the State of Bahia, as you will remember, are northwest-southeast and north into northeast-southwest. These lines get lost as we get farther north, and the trend of the coast itself changes north of Pernambuco. The change in the trend of the coast is accompanied by a similar change in the direction of the Serra da Borborema. The Serra da Borborema is more properly an eroded mass than a structural line, though it conforms quite closely to the general trend of this region.

"I consider the lines in the Ceara, Rio Grande and Parahyba true structural lines, as they are long lines of intruded granites and allied or similar rocks which indicate intrusions on or along lines of previous weakness. Part of these lines are indicated by the Ceara series of rocks which I have correlated with the Jacobina series of Bahia and with the Minas or iron-bearing series of Minas Geraes.

"I have never properly understood the forces that formed this fan-shape in northeastern Brazil. Just at what age it came is hard to say, as the age of the latest folded rock, the so-called Ceara series, is about Cambrian (for all we know, even pre-Cambrian). I believe that Derby considers the granites of southeastern Brazil to be post-Devonian, and I believe that these northern

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[8] It does not make any great difference, as far as the present conclusions are concerned, whether marine Tertiary does or does not exist in the above region. Professor Derby (1907) also expresses some doubt about the existence of marine Tertiary in the said portion of Brazil.

[9] It is beyond the scope of this thesis to attempt to discuss in detail any of these formations, excepting that of Alto Rio Amazonas. The necessity of this preliminary sketch will become evident after the reader has considered the ensuing topics. What has been land and sea is important from the standpoint of animal geography.

granites are in the larger part of an age younger than the Ceara series and somewhere along in the Devonian is entirely probable. You see between the Cambrian and the Cretaceous in the northern region we have no record.

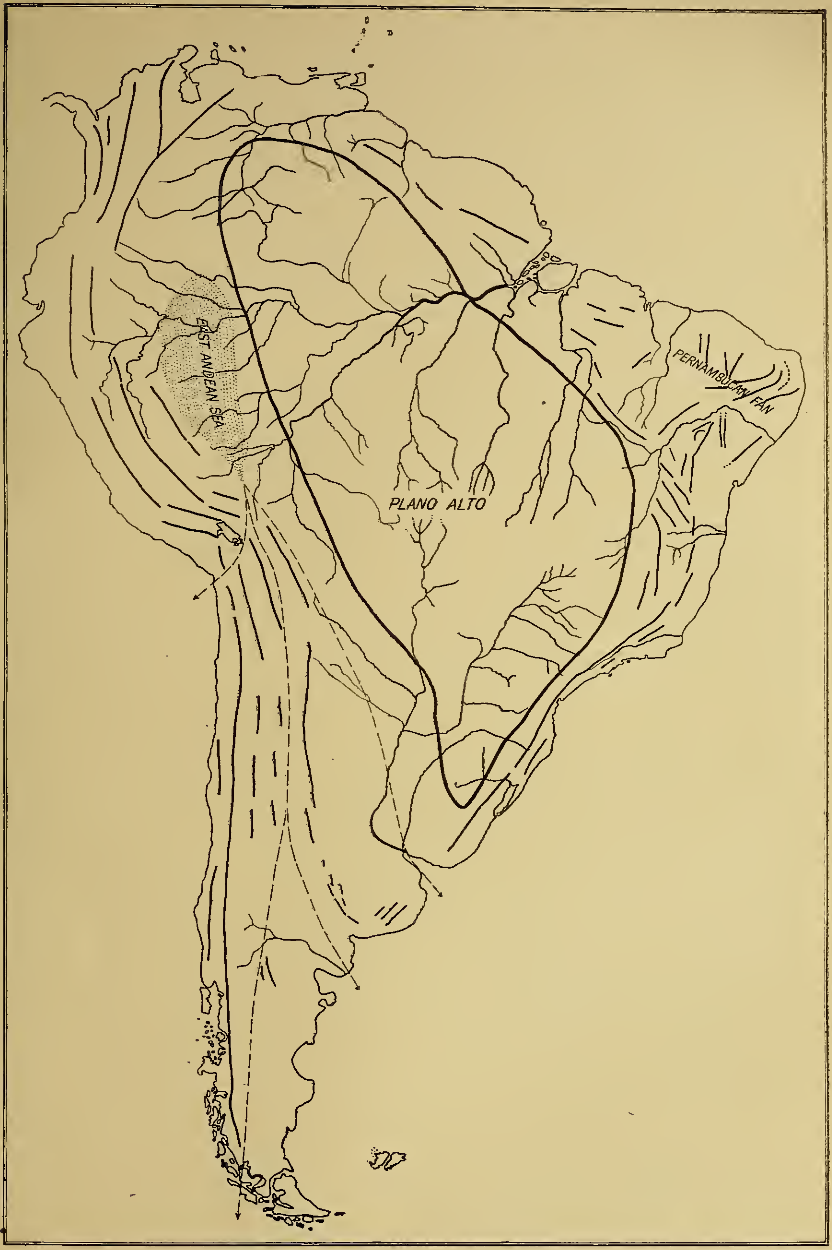
"It is entirely possible that the northern fan is due to local folding, but it is pretty large for that, that is to say, spread over a very large area."

I believe that these facts indicate that no Paleozoic wedge or land-bridge could have existed between this portion of Brazil and Africa, because the trend lines fade away toward the sea, and there is no evidence of the continuance of the lines across the Atlantic into Africa. The folds are crushed and irregular and do not end abruptly along the coast. Besides, if the wedge had existed, this type of fanlike folding would, I believe, have been almost if not quite impossible. This fanlike structure may possibly have been produced by some unknown force pushing from the interior of the earth at an angle to the vertical and more or less parallel to the coast, but more strongly in the region of the mouths of Rio Amazonas and Rio de la Plata, if the Brazilian coast was not connected with Africa. This would have pushed the southern and northern ends of South America to the west and have made the "Pernambucan fan" on the east and a somewhat similar structure in the region of Lake Titicaca east of the Bay of Arica.

In southern Brazil and more especially in all of the Plano Alto, erosion and extensive continental deposits have so disfigured the unexplored forested surfaces that little is known concerning the trend lines, but superficially this region looks like an abruptly chopped-off coast. This abruptness, I believe, is due to erosion of late and post-Paleozoic land deposits and not to post-Paleozoic faulting. The northwest strike from Cuyaba past the Madeira Falls, noted by Evans, may be due to ancient erosion, but I hardly think so, because the Plano Alto dips toward the southwest. The old drainage was into the East Andean Sea and hence the rivers at that time cut the Plano Alto in a western-southwestern direction. When the Amazon became reversed, Rio Madeira cut these old planes of erosion almost at right angles, producing thereby a very complicated topography.

By means of the trend of the Sierras de Tandil and de la Ventana, we can separate both of them from the Andean complex, in spite of the fact that Suess and Stelzner have been inclined to consider the Sierra de la Ventana as belonging to the Andean system.

In fact, the writer considers that the Sierras de la Ventana and Tandil with all of their side chains are the southern extension of the Cordova Mountains by the way of Sierra de San Luis, where there is a break in the system, just as the Serra do Mar of Brazil breaks up into several



OUTLINE MAP OF SOUTH AMERICA

Showing the trend lines about the Plano Alto and the hypothetical outlets of the East Andean Sea. The "Pernambucan Fan" has been put in from notes and maps contributed by R. Crandall.

chains in east central Brazil. I also believe that the above sierras originally formed part of the southern and western boundary of the great Permian Inland Basin which will be considered in the following pages.

I have relegated both the Sierras de Tandil and de la Ventana (as Hauthal did several years ago) to the Brazilian system for the following reasons:

1. The Sierras de Tandil, de la Vantana, de San Luis and de Cordova, like the Serra do Mar of Brazil, are characterized by an almost entire absence of marine fossils and have no marine Tertiary and Mesozoic, which is characteristic of the Andean complex.

2. In general succession, the Archean rocks of these sierras resemble the Serra do Mar rather than the Andean system.

3. These sierras are well separated from the Andean complex by many elevations and depressions, some of which afford evidence of Mesozoic and Tertiary invasions of the sea.

4. From the absence of fossils, it may be judged that these sierras have remained almost stationary; and as a result, there is a striking correspondence between their altitudes and those of Brazil and Guiana.

It is possible from similar reasons that at least part of the Cordilleras Oriental of the northern Andes will be shown to belong to the old Brazilian system, but entirely too little is known about this region to warrant a consideration at this time.

The trend lines of the Pacific side are also parallel to the coast. In the region of La Paz, Bolivia, there is an indentation of the coast back of which the chains of mountains are bent out of line and piled up to several thousand feet of altitude. This region is, in a way, the counterpart of the fan-shaped region of Pernambuco along the Atlantic Coast. In other words, the trend lines of the two coasts exhibit a remarkable similarity, as is indicated in a general way on Plate XI. The only striking difference is that in the region of La Paz, Bolivia, the coast is bent in, while it is bulged out in the region of Pernambuco. Taylor has attempted to explain part of this by a sliding of the Brazilian mass against the Andes. This sliding was assumed to be due to some force applied parallel to the Brazilian coast but having a greater intensity in the regions of the mouths of the Amazon and la Plata.

The lines of weakness and strength in a general way extend north and south (as Schuchert has shown for North America). This is shown by the maps of the marine deposits. The invasions of the sea as a rule appear to have been from the south toward the north. The Permian of southern Brazil or the Devonian extending from the Amazon Valley past Cuyaba into Parana, and perhaps as far south as Sierra de Tandil, if the (?) Devonian of Siemiradzki exists there, are good examples of a southern-northern invasion of the sea. In all of this region, an east to west invasion of the sea appears to have been impossible, excepting in narrow belts along the coasts, on account of the intervening Archean mountains, like Serra do Mar, which show no traces of marine deposits.

This is of the utmost importance from the standpoint of animal distribution. Some authors have attempted to show that the Patagonian region, and others that the Guiana region, was for a long time cut off from Brazil by arms of the sea. In order to isolate either of the above regions from Brazil, it would require an extensive east to west invasion of the sea for which we have no evidence. On the other hand, the maps showing the location of marine deposits offer strong evidence against such a view. Either the older rocks of Chili or of the Cordova Mountains could afford connections between southern South America and the Brazilian region. Hence the observed difference in the fauna of Patagonia must be due in a great part to environmental conditions.[10]

BRAZILIAN COAST

In some respects, the Brazilian coast appears to be the counterpart of the contour of West Africa. Its abruptness is thought by many to be due to the submergence of a "wedge" which originally connected Brazil and Africa.

Soundings have shown that deep sea exists within a comparatively few miles of the Brazilian coast; but thus far soundings have not produced the slightest evidence for a submerged "wedge" or land-mass which is believed by many to have originally connected Brazil and Africa. In fact, there is strong evidence derived from soundings against the submergence of such an extensive land-mass into the abysmal depths.

This wedge must have been deeply eroded, forming thereby deep, wide and abrupt valleys. When this surface (such as Brazil at the present time) dropped beneath the ocean, few soundings would be needed to show that the bottom of the ocean under such conditions would not be uniform. Inasmuch as soundings have revealed no evidence in favor of such a rough sea bottom, I take this as strong evidence against such a view.

It is true that Murray has found a mid-Atlantic ridge, but the trend of this elevation is parallel to the distant coasts, *i. e.*, more or less north and south and not east and west.

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[10] Also the imperfection of the fossil records, exploration, etc., in South America cannot be ignored. I saw part of a *Toxodon* from near Uruguayana, Brazil. Even if an arm of the sea separated Patagonia from the rest of South America, it would have been entirely too narrow to have been an effective barrier.

Soundings as well as fossils indicate that the Brazilian coast at one time extended slightly farther east than at present. There appears to be little or no doubt that the Abrolhos and Barbados islands were originally connected with South America (? late Mesozoic). To the east of these islands, no shallow sea or numerous small islands exist, as they do in regions like the West Indies, East Indies and Alaska, where we know that elevations and subsidences have taken place.

The abruptness of the present Brazilian coast is not necessarily evidence in favor of a post-Paleozoic faulted coast. In fact, my own observations have convinced me to the contrary. The entire absence of fossils along the coast of southeastern Brazil indicates a great stability of this region. Inasmuch as in all this region nearly all of the rivers flow west and southwest, away from the ocean, it appears that there is a gentle dip towards the southwest. Of course much of the surface of this region is covered by late and post-Paleozoic continental deposits which have been deeply eroded. The erosion of these deposits as well as the older rocks would produce an abrupt appearing coast just as is seen on the north and east sides of isolated mesas, or portions of the old Plano Alto, which will be taken up in the following pages. Therefore, I believe that the abruptness of the southeastern coast of Brazil is due to its stability, as is shown by the absence of fossils, and to the southwest dip of continental deposits, especially of late and post-Paleozoic age which have been deeply eroded, and not to a post-Paleozoic faulting and sinking of a land-mass into abysmal depths, for which no positive geological evidence exists. Much of the abruptness, however, is nothing more than sea cliffs.

During Cretaceous times, there was a slight elevation of the coast of central and northern Brazil. In comparatively recent times, the entire Brazilian coast has risen 40 feet.[11] This is sufficient to change the earlier coast line and to produce another line which is abrupt, but due to ages of erosion and not to faulting. Moreover, there are analogies for this abrupt coastal condition in which no extensive sinking of a land-mass has occurred.

Therefore, summing up all the geological evidence, the lack of east

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[11] Hart, Krone and others have stated that the Brazilian coast has been elevated about 40 feet since the Pleistocene or Quaternary. I had ample opportunity to confirm this view while traveling in Rio Ribeiro de Iguape and along the coast at various other points of southeastern Brazil. The location and nature of the sambaquis (shell mounds), the ocean caverns and wave marks along the bases of inland morros (hills) show that the sea extended inland almost to the mouth of Rio Juquia (west of Iguape) even as late as the time of the Indians in this region. In further evidence of this, marine shells are dug up in wells east of Campos along the Rio Parahyba and along the west shore of Lagoa Feia, which is now about eight miles from the seashore and about nine feet above sea-level.

and west structural lines, the deep intervening sea, absence of islands, relative evenness of great ocean depths, the absence of the deposits found in deep seas on the continental shelves and the shape and abruptness of the coast due to ages of erosion assisted by recent elevations, we conclude that South America could hardly have been connected with the eastern hemisphere.[12]

PLANO ALTO AND THE PERMIAN INLAND BASIN

I have used the native term, Plano Alto, to include all of the sand-capped tableland which extends south from the Guianas through Brazil into Uruguay and west into Bolivia. The outlines of this region are shown on Plate XII. All of these highlands appear to have been deposited in a fresh-water inland basin during the Permian epoch. The remains of Permian reptiles (*Mesosaurus* and *Stereosternum*), of the Gondwana flora and other plants, of *Scaphonyx*, a Triassic reptile, of *Schizodus*, *Conocardium*, *Myalina* and a few other marine lamèllibranchs found in the highland region indicate that the Plano Alto was deposited by wind and rivers in a fresh-water inland basin of Permian age. The thin layer of intercalated marine limestone indicates only a brief Permian invasion of the sea in the Plano Alto of southeastern Brazil.

The Permian Inland Basin was almost surrounded by Archean mountains: on the east by Serra do Mar and its northern spurs; on the south and west by the Cordova Mountains and their southern spurs; on the north by Archean rocks of Guiana and Venezuela, and on the northwest perhaps by the Cordillera Oriental. The characteristic sandstone found in all of this region was in part deposited in shallow fresh water and in part shuffled about by winds into this Permian basin.

The basal Plano Alto formation or the floor of the Permian inland basin is composed of granites, gneisses, crystalline schists and the like, which are generally considered pre-Cambrian or Archean, because of the absence of fossils. On various portions of this basal formation are Paleozoic deposits which have already been mapped, but which will without doubt be greatly extended as exploration proceeds. These maps show that none of the Plano Alto included in Plate XII has been invaded

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[12] The absence of marine Lower Carboniferous fossils from eastern Brazil is not, in my opinion, nearly as strange as the apparently entire absence of post-Paleozoic marine deposits of southeastern Brazil, in view of the fact that west of Serro do Mar are found marine deposits of Devonian and Permian age. The first great escarpments in British Guiana, not far from the coast, are due to the erosion of the Plano Alto sandstone in the regions of the Kaieteur Falls; similar conditions exist right along the coast of southeastern Brazil. So it will take far better evidence than exists to prove that this coast of Brazil is a post-Paleozoic faulted one and not a Paleozoic one which has remained stable and has been changed by the erosion of later land sediments.

MAP OF PART OF SOUTH AMERICA

Showing the outline of the Plano Alto, which was deposited in the fresh-water Permian Inland Basin and contains no Post-Paleozoic marine deposits

by post-Paleozoic seas. Hence continental and not marine deposits are the more extensive deposits of Brazil.

The Permian inland basin is not uniformly symmetrical in reference to the altitude of the basal rock in different sections, but its northern and eastern sides are always higher than the southern and western. There is also a considerable elevation of this basal formation between the headwaters of Rio Paraguay (also seen in the iron and manganese deposits 600-800 meters above the level of Rio Paraguay in the Serra de Urucum) and the Amazon, but this may be due to unequal early Paleozoic erosion. This is especially true, if the streams flowed westward before the Amazon was reversed. This difference in elevation of the pre-Cambrian and early Paleozoic or basal formation of the Plano Alto was of the utmost importance for the formation of the Plano Alto. The overlaps near these various higher (?) Archean elevations indicate that much of the basal sandstone of the Plano Alto was derived from place erosion of the higher points of the floor of the Plano Alto. Hence no considerable extension to the east of present coast of South America was necessary. The uppermost strata were deposited from the higher Archean mountains on the east and northeast and hence dip toward the southwest.

The outlines of the Plano Alto shown on Plate XII may be slightly extended by future work from southeastern Brazil toward Argentina, farther into Paraguay and Bolivia, and farther west from Brazil toward the Cordillera Oriental of Colombia and Ecuador. So much of the Plano Alto has been deeply eroded and some entirely washed away that its exact limits cannot be given at the present time.

It is evident from Plate XII that the Plano Alto proper is bounded by parts of the basins of Rios São Francisco, Orinoco, Mamoré and various other smaller rivers as well as by waterfalls and other changes in the geological structure. In this connection, it is interesting to note that all of the rivers which rise in the Plano Alto have clear water at least as long as they flow on its formations, while many of the bounding rivers which flow from the surrounding mountains often have yellow muddy water. Rio Bermejo of Argentina, Rio São Francisco of Bahia, Rio Mamoré of Bolivia, Rio Solomoes of Brazil, Rio Gurgueia of Piauhy and Rio Colorado[13] of northern Patagonia are good examples of such rivers.

The yellow mud carried by all of these rivers, excepting Rio São Francisco, is produced for the most part by the erosion of Mesozoic and Tertiary marine deposits; and inasmuch as these formations are not known

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[13] From the size of the lower valley of this river and the identity of its fishes with those of Rio San Juan, I am convinced that Rio Colorado was formerly much larger and must have had some headwater from southwest Bolivia.

to exist in the Plano Alto, the yellow rivers assist in a most interesting way to separate the Plano Alto from the rest of South America.

The original surface of the Plano Alto, as well as its uppermost strata, dipped gently as a whole toward the southwest. This broad conclusion is based on the following facts, after due allowance is made for ages of erosion, reversal of rivers and the Tertiary rise of the Andes.[14]

1. All of the streams and rivers which rise on the Plano Alto, *i. e.*, on the Permian sandstone, at first flow south, southwest or west, even though they afterwards flow north and east, *i. e.*, after they are eroded deeply into the lower strata and flow over the older Paleozoic and Archean rocks. For example, Rio Guaporé flows at first about 200 miles south and then makes an elbow bend and flows west, north and lastly northwest into Rio Mamoré. The streams of Jalapão in northern Goyaz, the headwaters of Rios Parana and Paraguay and the streams of the Guiana highlands all exhibit these same conditions in their headwaters. Even if stream piracy is said to be responsible for these conditions, the general dip would still be toward the southwest, because piracy could only be produced by the more rapidly flowing northern and eastern streams robbing the headwaters of the streams which flow toward the southwest, in order to explain the existing conditions. The cases of stream piracy considered in the following pages show that it has been produced in exactly this way.

2. The second fact which supports the southwest dip of the Plano Alto is that the north and east faces of isolated mesas or portions of the original (not secondary) highlands are almost perpendicular, while the south and west sides usually have gentle slopes. This is beautifully shown by the Urucum Mountains near Corumba and by the many isolated mesas in the Jalapão region of northern Goyaz. Also the west face of the Serra de Parecis east of Villa de Matto Grosso is not nearly so perpendicular as the east face of the Serra de Ricardo Franco, west of Villa de Matto Grosso. The high Kaieteur Falls of an east-flowing river of British Guiana and the Rio Branco flowing west from the same region having only rapids support the same conclusion, *i. e.*, the surface of the original Plano Alto dipped as a whole toward the southwest.

In view of all this, there appears to be no doubt that the Plano Alto was previously much larger than generally considered. It has been very stable since the Permian epoch. These facts may indicate a vast center of evolution of plants and animals, but I hardly think so, for even at the present time few plants and animals are able to thrive on this sandy elevated region. In Permian and Mesozoic times, perhaps, this region was

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[14] The dip is so gentle that it is difficult to detect in the strata at exposed surfaces.

somewhat arid on account of higher, surrounding older mountains, but even if it had sufficient rainfall, on purely lithological grounds, a luxuriant vegetation and fauna would be impossible, because a sandy soil does not retain the necessary constituents for a luxuriant growth of plants. Besides, it appears more probable that unstable regions would produce greater changes in living things than stable regions. Hence, not until the Plano Alto was deeply eroded, could we expect to find a luxuriant growth of vegetation and a complex fauna. Also, the Triassic Parana trap which spread over much of the highlands of the states of Parana and São Paulo of southern Brazil may have been an important factor in exterminating and affecting the plants and animals, such as perhaps the Gondwana flora and Permian reptiles which are discussed in the second part of this thesis.[15]

EAST ANDEAN SEA

Several years ago, Professor Orton, Barrington Brown and others collected marine or brackish water fossils mixed with fresh-water forms along the Alto Rio Amazonas.

The following is a list of the fossils which have been ascribed to Alto Rio Amazonas by Gabb, Conrad, Etheridge, Woodward and Boettger:

- *Anisothyris tenuis* Gabb
  - *carinata* Conrad
  - *obliquus* Conrad
  - *erectus* Conrad
  - *cuneatus* Conrad
  - *ovatus* Conrad
  - *hauxwelli* Woodward
  - *tumida* Etheridge
  - *amizonensis* Gabb
- *Neritina (Isæa) ortoni* Gabb
  - *pupa* Gabb
  - *puncta* Etheridge
  - *ziczac* Etheridge
- *Hydrobia lintea* Conrad
  - *confusa* Boettger
  - *tricarinata* Boettger
  - (*Dyria*) *gracilis* Conrad
- *Hydrobia dubia* Etheridge
- *Lacuna* (*Ebora*) *crassilabra* Conrad
  - (*Nesis*) *bella* Conrad
- *Hemisinus sulcatus* Conrad
- *Melania tricarinata* Etheridge
  - *bicarinata* Etheridge
  - *scalaroides* Etheridge
- *Dreissenia fragilis* Boettger
- *Turbonilla minuscula* Gabb
- *Corbula canamænsis* Etheridge
- *Melanopsis browni* Etheridge
- *Cerithium coronatum* Etheridge
- *Pseudolacuna macroptera* Boettger
- *Assiminea crassa* Etheridge
- *Bulimus linteus* Conrad
- *Anodonta batesi* Woodward

Fragments of the following genera have been reported by Woodward: *Myliobatus, Fenella, Thracia, Lutria, Anodon, Unio, Nautica, Odonstomia*. Boettger has also reported *Serpula* (Vermes) and *Rajidum* and

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[15] It is to be noted here that similar Permian and Triassic continental deposits exist in other parts of South America (Ceara, Brazil, San Luis, Argentina, etc.) which are not included in my Plano Alto, because they have been separated by marine deposits.

Percidarium (Pisces). Etheridge has reported parts of *Chara* (Plantæ). Fossil tortoises and *Mosasaurus* also are said to have been found along Rio Acre. These fossils are then a mixture of fresh-water, land, brackish water and marine forms which lived apparently in a very special environment.

In reference to the age of the above fossils, I can do no better than refer to Vol. XLIV of the Bulletin of the Museum of Comparative Zoölogy, Harvard, pp. 25-27. In this résumé, Professor Branner states:

> "If we grant that the upper Amazon region from Iquitos to Tabatinga is Tertiary, there is no evidence that the mottled sediments of the lower Amazon are of the same age, to say nothing of correlating them with similar looking beds on the coast of Rio Grande do Norte, Parahyba, Pernambuco and Alagoas, 2500 miles away. This seems also to express Professor Derby's view of the subject."

Professor Branner also quotes Dall as saying that:

> "The Pebas fossils are unique and difficult to determine the age because the characteristic forms are extinct and have no obvious relatives. They may be as old as Eocene or as young as Pliocene."

The maps of the location of the marine formations show that the entire Plano Alto as herein mapped is Archean and Paleozoic; while the Andean complex has an Archean nucleus more or less covered by marine deposits of Mesozoic, and marine Tertiary is known to exist along both bases of the Andes almost for their entire length. The trend lines of this region are north and south, and they strongly indicate an extension of the East Andean sea in the same directions.

The deposits along Alto Rio Amazonas are known from Pebas, Peru, down Rio Solomoes as far as São Paulo de Olivenca, and south along Rio Javary and Rio Acre. My maps show that this region lies between the Cordillera Oriental of the northern Andes and the Plano Alto. It must also be remembered that nowhere east of São Paulo de Olivenca, which is 1400 miles in a straight line from the mouth of the Amazon, have similar or any post-Paleozoic marine deposits been found. This fact, as well as others which have already been considered, strongly indicates that the sea did not invade the Amazon Valley from the east, because the Plano Alto would have been a permanent barrier to such an invasion from the Permian to comparatively recent times.

The dip of the Plano Alto and the character of the sediment carried by the Rio Negro, as well as the fact that no positive evidence exists which warrants a northern extension of the East Andean Sea into Venezuela, indicate a southern extension of the East Andean Sea, because as far as I have been able to find, no Mesozoic and Tertiary are known to exist east of the Cordillera Oriental of Ecuador or in the southern parts of either Colombia or Venezuela, *i. e.*, as far south as the headwater of Rio Negro in the Brazil-Guiana highlands. This vaguely indicates a connection between these Archean mountains of eastern Colombia (Cordillera Oriental) and the Plano Alto, but inasmuch as this region is practically unknown, too much emphasis must not be placed on such data.

There is then no positive evidence for either a northern or an eastern extension of the East Andean Sea, but there is some positive evidence for its southern extension. The location of the marine formations, the dip of the surface of the Plano Alto and the character of the sediment carried by southern Andean affluents of the Amazon vaguely indicate the same. The southern extension of Cretaceous deposits from the headwaters of Rio Maranhão south toward Cochabamba is a good example of the southern extension of part of this East Andean Sea which finally lost its connection with the ocean on account of the Tertiary rise of the Andes.

In reference to the connection of this East Andean Sea with the ocean, the following points are important:

1. Stelzner (1873) reported a sandstone containing marine bivalves of (?) Tertiary age from Santa Maria, Catamarca of northern Argentina.

2. Brackenbush has reported marine or brackish water fossils of (?) Cretaceous near the headwaters of Rio Bermejo which flows into the Gran Chaco del Argentina. Melania was the most abundant form found, and it may be that these deposits are fresh water and not marine.

3. Far to the west of the above regions, there is a great depression in the Andean complex east of the bay of Arica and south of Lake Titicaca, but so far there is no good evidence of a Tertiary sea passing over the top of the Andean complex.

4. It appears to be obvious from the characteristic fossils of the upper Amazon Valley that a direct and broad connection with the ocean did not exist. If, as the Cretaceous fossils of the Alto Rio Maranhão indicate, the East Andean Sea existed during at least part of the Mesozoic to some time in the middle or late Tertiary, there would have been ample time to evolve this peculiar fauna of Pebas, because the conditions which would have existed in this long, slender inland sea, into which many short rivers carrying sediment flowed, would have been very different from those of Patagonia, la Plata or along the Pacific slope.

It appears that the fossils of Alto Rio Amazonas are the last of the fauna of the East Andean Sea which became buried in the mud carried by the rivers into this vanishing sea, because the molluscs died with their valves closed and because there are some fresh-water and land molluscs mixed with the marine forms.

In conclusion, then, we may say that the age of the fossils of the upper Amazon Valley is not definitely known, and consequently we cannot more than conjecture where the East Andean Sea joined the ocean;[16] but this sea must have extended south and have had a narrow connection with the ocean in the region of either Rio Bermejo, Rio Colorado-Patagonia or the bay of Arica. This connection was perhaps not broken before the Miocene, but it was broken by the Tertiary rise of the Andes. It is also important to note that no evidence is yet known which indicates that the exit of this sea simultaneously cut east by west both the Archean mountains flanking the northeast portion of Patagonia and those on the western side of Patagonia in Chile in such a way as to isolate Patagonia from Brazil. In fact, the evidence at hand is all against such a view.

REVERSAL OF RIO AMAZONAS

The following facts indicate that the direction of Rio Amazonas has been reversed:

1. The Plano Alto which it now traverses has a general southwest dip.
2. The entire absence of marine Mesozoic and Tertiary fossils in the Plano Alto.
3. The position of the East Andean Sea.
4. The Tertiary rise of the Andes.
5. The general north and south direction of trend lines and the location of marine deposits in western South America.

In an interesting treatise on the geology of the lower Amazon, Katzer (1903) concluded that previous to the Miocene the Amazon flowed west from somewhere in the region of Rio Paru. To the east and north of the present mouth of the Amazon, he conceived a vast mass of land which sank beneath the Atlantic Ocean when the Amazon became reversed.[17]

Katzer also states that, during the reversal of the Amazon, a large lake was formed, which extended eastward from Rio Nauta to the original watershed. It appears that he has assumed the formation of this huge lake in order to explain the formation of the fresh-water deposits of Ereré. Katzer also maintains that no marine Cretaceous or Tertiary beds exist in the lower Amazon Valley (Pirabas Cretaceous being on the

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[16] I am inclined to believe that it extended south along the east base of the Andes into Patagonia, because there is no evidence of an eastern extension, a western over the Andes, a northern into Venezuela. The connection by way of Gran Chaco is very questionable, for I believe the Plano Alto of eastern Bolivia joins the northern extensions of the Cordova Mountains. Hence a southern extension into Patagonia meets no obvious objection.

[17] Pilsbry (1911) has also suggested the same idea in his studies on the distribution of fresh water and land mollusca. It is interesting to note that three individuals working in different fields have quite independently arrived at the same general conclusion.

coast) and that (?) Archean rocks underlie the alluvial deposits of the Amazon and are continuous with the basal rocks of the highlands on both sides of the Amazon.

The writer has independently, and from a slightly different standpoint, arrived at the same general conclusion, namely, that the Amazon is a reversed river, but he differs with Katzer in regard to the following details:

1. The writer does not believe that there is any geological evidence which even vaguely suggests either the existence or the submergence of the hypothetical land-mass to the east and north of the present mouth of the Amazon River. In fact, just south of the mouth of the Amazon are marine Cretaceous fossils which indicate a slight elevation of the present mouth of the Amazon from the sea and not a continuation to the east with a hypothetical land-mass.

In this connection, no support for the hypothetical old land-mass can be derived from the Barbados Islands, because they are entirely too far to the north and belong to the Antillean complex. Both the absence of islands and the deep-sea soundings are strong evidence that, previous to the Miocene, no land existed east and northeast of the present mouth of the Amazon across the Atlantic Ocean.

In fact, there is no necessity for the assumption of the submergence of any great mass of land to the east of the present mouth of the Amazon, not even to form a watershed, because many rivers, like Rio Parahyba, Rio Tieté, Rio Iguassú, etc., of southeastern Brazil, rise within a few miles of the Atlantic Ocean and then flow several hundred miles before entering it.

2. The reversal of Rio Amazonas from the region of Rio Parú is roughly comparable to the supposed reversal of the Mississippi from the region of New Orleans instead of nearer its headwaters. That is to say, the comparatively recent reversal of the Amazon will have to be, I think, in the region where the most of its large affluents enter it, namely, somewhere between Manaos and Santerem; because Rios Madeira, Solomoes and Negro, which make the main stem of the Amazon, come together just below Manaos. There is topographical evidence which shows that the Rio Negro formerly entered the Rio Solomoes above its present mouth, and hence the eastward extension of its mouth indicates that its present mouth is near the region where the Amazon began to cut through the old watershed, *i. e.*, near the dissected western base of the original Plano Alto which has been washed away by the Amazon.

The arrangements of the low secondary sierras in the region of the lower Rio Tapajos on the south side and near Obidos on the north side of Rio Amazonas, taken along with the fact that the Amazon flows in one channel only in two places (just below the mouth of Rio Madeira and near Obidos), also strongly indicate that this is the region of the previous watershed. Is it not to be expected that some trace of the original watershed would still remain, if the reversal of the Amazon took place during the Miocene? There certainly is not the slightest suggestion of such a divide between Santerem and the mouth of the Amazon, because the Amazon is so wide and swampy in all of this region, and this is especially true in the region of Rio Parú. Below Santerem, the Amazon has many channels and many islands; between Santerem and Manaos, there are two places where the Amazon flows in one channel, and above Manaos Rio Solomoes (Amazon), there are again many channels and many islands.

In view of all this, it appears that the original watershed must have been somewhere between the mouths of Rios Madeira and Tapajos, and I think that Obidos is near the actual point of reversal.

3. I also do not believe that there is any evidence of a huge lake which extended eastward from Rio Nauta to the old watershed. This old view of Tertiary lakes has been ably combatted by Hatcher, Matthew and others, but it will perhaps be worth while to consider the formation of highland deposits in order that the fresh-water deposits of Ereré of the lower Amazon as well as the other supposed evidence for a colossal Amazonian lake will have an explanation. In the following brief consideration, I have chosen the headwaters of Rio Guaporé, but those of Rio Paraguay are equally as instructive.

Many streams, headwaters of Rio Guaporé, dash down the more or less perpendicular faces of the so-called sierras from the flat surfaces of the dissected Plano Alto into a large semicircular valley. This valley includes the extensive Campos de Matto Grosso. Farther down this valley, the campos are replaced by gigantic forests which encroach upon the Guaporé so much that its channel is almost stopped up in several places below the Villa de Matto Grosso.

In this same region, the Serras de Ricardo Franco and de Parecis (made by the Guaporé dissecting the Plano Alto) are much nearer to the river than in the region of the semicircular valley. This serves as a block to the exit of the water which falls above this point. The dense forest, fallen trees and water plants naturally assist in storing the heavy rains which fall in the semicircular valley during the rainy season (November to April).

In the middle course of the Guaporé, its channel widens very much. Tremendous sand bars are encountered in each bend of the river. This condition is replaced in the lower course of the river by a series of rapids. after which it enters the Mamoré.

The Guaporé has then two great regions where sediments of different nature are deposited at different altitudes and two great regions where the water runs rapidly and carries away the eroded product.

It is the highland semicircular valley which, I believe, is roughly comparable to the Serra de Ereré. This region is flooded yearly during the rainy season, at which time much sand is deposited. This deposition of sand and other material (laterite, etc.) will eventually make a secondary deposit of considerable extent, while the regression of the headwaters of Rio Guaporé will eventually carry away all of the original Plano Alto remaining in the surrounding Serras de Parecis, Ricardo Franco and Agoaphey.

In fact, the Guaporé has already carried away more than one half of the original highland formation from this region. The Rio Paraguay is naturally assisting in this destruction of the "highest point." As soon as these two large rivers have obliterated the above mentioned sierras, the semicircular highland valley will become one of the highest points (300 to 600 meters). After years of erosion on such a new high point, isolated sections or mesas will be formed and secondary sierras like that of Ereré will be produced which never were associated with colossal lakes.

I have observed near Corumba, Brazil, a similar deposition of leaves, snails, etc., at two distinct levels. One of these levels is around the base of the Serra de Urucum, including even deposits of limestone, and the other is in the near-by pantanals (swamps) of Rio Paraguay. The same process is going on near São Luis de Caceres, Brazil, and San Matias, Bolivia.

Hence there is no evidence for a huge Amazonian lake and no necessity for assuming one, for, as the writer conceives the reversal of Rio Amazonas, it was a gradual process. The Tertiary rise of the Andes did not suddenly close the exit of the East Andean Sea. but the water cut deeply at the exit, until by the time this exit was almost closed, stream piracy in the region of the old divide (near Obidos) had prepared a new exit for the water of the shallow East Andean Sea. For some time, then, there were two exits for the East Andean Sea. As the Andes rose higher and higher, the southwestern exit became closed and all of the water rushed eastward. The amount of this water flowing eastward was sufficient to wash away the old divide in a comparatively short time.

Even the Rio Guaporé has washed away the most of the Permian formation of the Plano Alto from a strip 50 to 150 miles wide. Is it not plausible, then, that the massive Amazon could have opened up its present wide swampy valley and built up an extensive delta in a comparatively short time?

That the Amazon has swampy margins is no more an objection to its reversal than the original swampy margins of the Mississippi would be to its reversal. The Amazon, like the Mississippi, if it was reversed, has washed away the most of the old divide.

Little or no exploration has been done far away from the forested margins of the lower Amazon and its affluents. But an inland trip in any of the region between Santerem and Obidos will usually reveal sandy campos which are typical of the entire Plano Alto formations. When this region is carefully explored, I feel sure that the old divide will be definitely located.

The view which I have expressed concerning the East Andean Sea offers a ready explanation of the origin of the peculiar marine-like fauna found in Lake Titicaca. Lake Titicaca was doubtlessly once connected with the East Andean Sea by a stream. When the East Andean Sea began to disappear, some of its fauna entered or was cut off in the Titicaca basin. When the Andes rose still higher, the amount of rainfall became more and more reduced until the exit of Lake Titicaca became severed.

Eigenmann[18] states that Steinmann considers that the Titicaca basin was a fresh-water basin whose southeastern exit was dammed by glaciers. Glaciers may have assisted in closing the exit of Lake Titicaca, if they were active at the time when the rainfall was so much reduced that the precipitation scarcely exceeded evaporation; but it is evident that the reduction of the rainfall due to the rise of the Andes was the more important factor. Otherwise, heavy rains would soon have filled up the basin sufficiently to make a new exit. The Great Lakes of North America were glaciated, and yet they made new exits.

The absence of *Manatus, Arapaima* and *Osteoglossum,* above the Madeira Falls and their presence above the falls of Tocantins, Tapajos, and in some of the coastal streams north and south of the Amazon are exactly what one would expect to find according to all of the facts which have been considered. These three genera originally lived in the coastal streams. When the Amazon became reversed, the Mamoré, which had previously flowed southwest, changed its direction and suddenly formed the Madeira Falls, which have been barriers to the migration of these three genera.

Further zoölogical and topographical data could be given in support

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[18] Princeton Patagonian Reports, Pt. III, p. 372. 1909.

of the reversal of Rio Amazonas, but inasmuch as the most of it is not sufficiently decisive to account for such a momentous geological change, it has been omitted; for such data may be said to harmonize equally well with any view of the region in question.

Finally, in reference to the time of the reversal of Rio Amazonas, I may restate that Katzer has placed it in the Miocene. It appears that it could not have been before that epoch, but until the exact age of the "East Andean fossils" has been determined, we cannot settle this most important question with any degree of certainty. The determination of the exact age of the fossils from Alto Amazonas and the exact location of the exit of the East Andean Sea offer alluring opportunities for future exploration.

STREAM PIRACY

On the divides between various South American rivers, the headwater streams sometimes approach one another with closest intervals. This is particularly true of the divides on the Plano Alto. For example: Rios São Marcos and Bartholmeo of Rio Parana; Rios Bezzero, Jardin and Preto of Rio Paracatú and Rio Urucupa, both of which flow into Rio São Francisco, and Rio Parana, an affluent of Rio Tocantins. All of these rivers flow from brejos (swamps or sloughs), Lagoa Feia and other highland lagoons between the villages of Paracatú and Formosa of southeastern Goyaz. In fact, these headwaters of three large river basins rise in sight of each other from brejos which vary from 1100 to 1147 meters of altitude, and the maximum altitudes of the intervening sand hills are never more than 1177 meters.[19]

Stream piracy (coalescence of streams) may have existed on a very limited scale between the following rivers—at any rate, their headwaters are not far apart:

1. Rio Ribeira de Iguape (? robbed Rio Capella) and Rio Paranaponema.
2. Rios São Francisco and Doce and Rio Grande of the Parana near Carandahy and Miguel Burnier, Minas Geraes.
3. Rio Parahyba and Rio Tieté, Rio Parahyba having robbed its headwaters flowing south from Rio Tieté.
4. Rios Araguay, Xingu and Tapajos and Rio Paraguay.
5. Rio Ibicuhy of Rio Uruguay and Rio Vaccachy of Rio Grande do Sul.

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[19] The highland fauna and flora certainly interchange between these three river basins, but the typical Amazonian, São Franciscan and Paranean fauna and flora are at least one hundred miles away from this headwater region, *i. e.*, at a much lower altitude.

6. Rio São Francisco and Rio Itapicurú east of Joazeiro.

7. Rio Agua Branca and Rio Negro of Rio São Francisco and Rio Palma of Rio Tocantins.

8. Rio Grande of Rio Mamoré and Rio Pilcomayo of Rio Paraguay.

9. Rio Branco of Rio Negro, Rio Parú, Rio Trombetas and Rio Essequibo.

10. Corrego da Boa Ventura of Rio Guaporé and Corrego de la Fortuna of Rio Paraguay.

Even if these streams, however, were previously connected, the connection would have been so small and at such altitudes that nothing but the highland fauna could have interchanged. Besides, all these streams have and have always had waterfalls in some part of their courses.

Plate XIII shows in a general way that no continuous waterway exists between Rio Paraguay and Rio Guaporé, as has been so often erroneously stated. Several years ago, an attempt was made to cut a canal between Rio Guaporé and Rio Jaurú, but it was given up on account of the intervening distance (about 20 miles) and the nature of the material to be removed. A grandson of the man who attempted to make this canal hauls rubber over this divide in an ox cart, but it is far more difficult than by the Bolivian trail from San Ignacio past San Matias to Descalvados.

The former trail (Villa de Matto Grosso by the way of Jaurú to São Luiz de Caceres) is only 301 kilometers long, while the latter trail (Villa de Matto Grosso to Bastos, las Encruzijadas, San Matias and Descalvados or São Luiz de Caceres) is 488 kilometers, but it is much smoother. While following this latter trail, I had ample opportunity to observe that no connection exists between the Rios Alegrete and Agoaphey. In fact, Rio Santa Rita flowing off this same sierra has one waterfall about 400 feet high. All of these rivers are nothing more than creeks.

The writer found that the nearest as well as the lowest approach between the headwaters of Rios Guaporé and Paraguay is in the region of the Corrego de Boa Ventura and la Fortuna; but even though there is a break in the continuity of the Plano Alto in this region, firm hills of considerable height separate these creeks, which are not more than ten feet wide and three feet deep and at least four miles apart.

Dr. Alipo Miranda de Ribeiro, Secretary of the Brazilian National Museum, was a member of the telegraph commission which has explored the northern portion of the Paraguay River. He explored Rio Jaurú and Sepatuba and found large waterfalls in each of these rivers. On the other side of the divide, the commission found two large waterfalls in Rio Juruena which flows into Rio Tapajos. One of these falls was about 400

HEADWATERS OF RIOS PARAGUAY AND GUAPORÉ, BRAZIL

HEADWATERS OF RIOS SAO FRANCISCO AND TOCANTINS, BRAZIL

Showing the connection between the two rivers. The hachures indicate the perpendicular face of the dissected Plano Alto. Scale: 1 in. = 71 km.

feet high. Similar conditions are said to exist between the headwaters of Rios Paraguay, Tapajos and Xingu, all of which rise on the Plano Alto and are not connected.

Stream piracy on a large scale has taken place between Rio São Francisco and Rio Tocantins and between Rio Negro and Rio Orinoco.

Rio Orinoco is robbing Rio Negro of one of its previous affluents, the Canal de Cassiquiare. This is due to the fact that there is a long gentle slope of the highlands toward the Amazon Valley, while the northern and eastern slopes are more abrupt. On account of these conditions, Rio Orinoco is still cutting rapidly and deeply through a so-called sierra just above its connection with the Canal de Cassiquiare. The Rio Negro on the other hand is not cutting as rapidly in this region as Rio Orinoco.

The Canal de Cassiquiare is a long, narrow, lakelike mass of water with high sand hills along and near either bank. The Rio Negro end of this "canal" is being gradually stopped up by secondary deposits of sand and plants, and consequently as soon as Rio Orinoco cuts more deeply into the hard basal highland rock, it will drain the Canal de Cassiquiare and appropriate it as an affluent.

Lakes and swamps similar to the Canal de Cassiquiare are quite common in and on all of the Plano Alto. Sete Lagoas, at the headwaters of Rio Paraguay, and Lagoa Feia, near Paracatú, in southeastern Goyaz, are examples of such lakes or swamps; but inasmuch as no marine deposits are known to exist in any of these regions, it appears that all such lakes are entirely due to unequal erosion and changes in the courses of the highland streams. Such is evidently the case of Canal de Cassiquiare, for it is almost surrounded by the highland sandstone, and in the regions of the upper waterfalls both Rio Orinoco and Rio Negro flow over the hard ancient basal highland rock. The rocks in the Rio Negro Falls are essentially the same as those of the Madeira Falls.

Similar conditions exist between the headwaters of Rio Tocantins and Rio São Francisco in the Jalapão portion of northern Goyaz. Wells (1875) and Froh (1907) reported a connection between these rivers; but my discovery, which was entirely independent, was based on the presence of certain Amazonian fishes not previously reported from the São Francisco River.[20]

Plate XIV shows that an affluent of Rio Tocantins and one of Rio São Francisco rise in the Brejo de Varedão, which is surrounded on all sides

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[20] It may be of some interest to note that I do not now consider that the presence of these fishes is evidence for this connection, because I later found the same fishes in other rivers where no connections exist. My erroneous assumption, however, which is a common one among static zoögeographers, led me to the discovery of several facts.

by massive sections (*i. e.*, faces of mesas, etc.) of the Plano Alto. These sections appear like many flat-topped sierras, but are nothing more than the perpendicular faces of the remains of a dissected plateau. From a distance, these sections look like gigantic modern fortresses; but as one approaches nearer and nearer to them, he notes that there are immense sand hills (campinas), which slope to and away from these sections of the Plano Alto. That is to say, the bases of the perpendicular faces of the sections are about 1000 feet below the top, while the tops of the campinas which join the same bases are often not more than 500 feet lower than the top of the sections. Hence the result of erosion is very striking in all the region of the Plano Alto, since the original high points tend to become the lowest.

The explorer is impressed by the great number of the highland brejos which flow along parallel lines and are about 6600 meters apart. These brejos are often less than 100 feet wide and usually have a small, rapid, clear stream in the center. The edges are so boggy and full of palms and other typical swamp plants that one often encounters great difficulty either in getting water to drink or in crossing them.

The Brejo de Varedão appears to be due to unequal erosion and a consequent deposition of sediment about the ends of the swamps. This region offers a peculiar case of stream piracy unless Rio Sapão has cut back into the headwaters of both Rio Nova and Rio Formosa. At any rate, the Brejo de Varedão is gradually being drained by Rio Sapão, which is cutting through the hard basal highland rock in its rapid descent to Rio São Francisco on one hand and by a similar action of Rio Formosa, which flows out of the opposite end of the same swamp to Rio Tocantins. During heavy rains, the Rio Nova still assists in draining this swamp. In fact, it is almost impossible to ride between its headwaters and the edge of the Brejo de Varedão, except during the dry season.

It was with great difficulty that the writer pushed his way through the swampy margins of the Brejo de Varedão to its lakelike central part, which could not be fathomed by the longest poles obtainable. In the middle, there was no current, but at the opposing ends were the rapid Rio Sapão and Rio Formosa, which at once leave the swamp, flowing over the basal highland formation. These streams are on the average 20 feet wide and four feet deep during the rainy season. At this time the Brejo de Varedão is about eight miles long and less than one mile wide at its widest part.

During the rainy season, a canoe can descend from the Brejo de Varedão with little difficulty as far as the great cataracts of Paulo Affonso of the lower Rio São Francisco; but a canoe cannot descend so easily from the Brejo de Varedão to Rio Tocantins, on account of a waterfall in the lower course of Rio Nova, known as Cachoeira da Velha.[21]

The Cachoeira da Velha is about 200 feet wide. It had, when I saw it, a small island with two trees. These trees are evidence that the channel was originally a few feet to the north of its present site, where there is still evidence of an old side channel which had no perpendicular falls. During half-flood season, I estimated the highest point of the falls at 24 feet. The north side was 12 feet and the south side was a rolling mass of water about six feet high. The south side has nearly all of the water, because there is an abrupt bend in the river about 500 feet above the falls. These falls are not any higher than the Theothono Falls of Rio Madeira, which have been passed by nearly all of the Amazonian fishes. It must, however, be remembered that Rio Madeira has a volume almost as large as the Mississippi and that the Theothono Falls are only about 100 meters above sea level, while the Cachoeira da Velha has a small volume of water and is at least 300 meters above the sea level.

The rocks of the waterfall are the same general type of (?) pre-Cambrian found in various waterfalls of the Plano Alto region. I picked up a piece of flint which I believe corresponds to the Jacuipe flint of Serra de Jacobina. To the northeast of this region, the iron, manganese and diamond-bearing gravels were observed near Paranagua, Piauhy. This indicates a similar structure as the Jacobina series of Bahia.

The dissected faces of the Plano Alto are far away from the south side of the Cachoeira da Velha and the river does not flow off of a mountain, as sketched by Froh. On the north side of the Cachoeira da Velha, there are several mesas of the dissected Plano Alto between Rio do Somno and Rio Nova.[22]

BARRIERS TO AQUATIC MIGRATION AND CONDITIONS OF ENVIRONMENT

Under the above heading, I will not consider physiological barriers, *i. e.*, if a fish is found in the upper course of a large river like Rio Paraguay, which is navigable by small ocean steamers, and is not found in the lower course of the same basin (Rio Parana), we may look on this restricted distribution as being due at least in part to a physiological barrier.

Under the subject of barriers to aquatic migration, I will discuss only one of the geological barriers, namely, waterfalls. Too much emphasis cannot be placed on the location, size and character of the numerous

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[21] It is so named because an old fish-like woman is supposed to have drowned a fleeing bad Indian at this point about 100 years ago. The natives are afraid to go to this waterfall.

[22] Canoes descend from Porto Franco on Rio do Somno to Pará during the rainy season.

waterfalls, because they mark changes in geological structure which are associated with profound changes in the environment of both aquatic and terrestrial life. The waterfalls are also very important, because they have been the source of some errors made by previous writers on the distribution of the aquatic forms. These errors have for the most part been due to a lack of exact data concerning the waterfalls.

The first of these great waterfalls is Paulo Affonso, which may be designated as the "King of Cataracts." Paulo Affonso is found in the lower course of Rio São Francisco and consists of a great series of rapids above and below the falls. The volume of water which rushes over Paulo its level 200 meters between Jatoba and Piranhas, a distance of 121 kilometers by the railroad which connects the navigable portions of the river above and below the real falls. In fact, the Rio São Francisco has lowered Affonso is on the average about the same as that of Niagara. Nearly all this "muddy" water comes from the precipitation in the headwaters of Rio São Francisco, its lower course from Joazeiro to Piranhas seldom having rain. Consequently, during the dry season, Paulo Affonso is much higher and more beautiful because the water is clearer. The relative difference in the height of Paulo Affonso during the dry and flood seasons is very great, because there are seven principal channels in the wide river above the falls through which the water rushes into the long, narrow gorge below the falls. I estimated the maximum height of a series of tumbles at 143 feet, but the flood-marks in the gorge below the falls for the preceding year, which had only an average flood, would have reduced this height at that time about 40 feet.

Of the seven principal channels at Paulo Affonso, the southernmost one on the Bahian side leaves the river about two miles above the falls and gradually rushes into the gorge below the falls. The natives claim that fishes swim up this channel during large floods, and I have no reason to doubt their statement, because I found that the fishes above and below the falls were almost identical, and because no great perpendicular fall exists in the southernmost channel of Paulo Affonso. Naturally the marine forms which enter the mouth of this river are not found above the falls, but *Pachyurus* (*Corvina*) is; and since it is never found in either Rio Novo or Rio Sapão, it must have originally passed Paulo Affonso, when it left the sea and became a permanent fresh-water form.

Finally, I may state that Professor Branner and one of his students, Mr. R. Crandall, have recently reported marine Cretaceous above Paulo Affonso at Jatoba. Consequently, Paulo Affonso did not exist at that time, but most of the present fishes of the São Francisco also did not exist at that epoch. There can be no doubt that Paulo Affonso is older than nearly all if not all of the fishes which are found in the Rio São Francisco. Therefore, Paulo Affonso appears not to have been a barrier to the migration of fishes.

In violent contrast to Paulo Affonso are the Iguassú Falls of Rio Iguassú. I say violent contrast, because the Rio Iguassú flows from the sandy highlands of Parana, Brazil, and after rushing over the Parana trap rock at several lesser waterfalls, finally tumbles over the Iguassú Falls and flows calmly toward the sea. The Iguassú Falls are about 200 feet high, and even though they are not exactly perpendicular, there are no side channels which could have been passed by fishes. The average volume of water is about one third more than that of Niagara Falls.

The Iguassú Falls tumble over the "Parana trap," which has been determined as Triassic by Professor Derby, and they are so old that they appear to have been an absolute barrier to the migration of the fishes. Above the falls, I found only about 25 species of small, common highland genera, many of which are slightly different from the same species in the neighboring highland streams. These differences, for all we know, may or may not be inherited, because the external conditions in the Rio Iguassú basin are different from those in the neighboring rivers. At any rate, the Iguassú Falls have been a permanent barrier to the migration of lowland fishes and the deplorably poor ichthyological fauna has for the most part evolved from the common highland fauna, which will be considered in the last part of this paper.

The next great South American waterfall which will be briefly considered is that of "Sete Quedras" (Brazilian) or "Guayra" (Guarani). The Guayra Falls are in the middle course of Rio Parana, between the State of Parana, Brazil, and the Republic of Paraguay. The Parana River above the falls is 4200 meters wide, and the water rushes through seven channels over seven falls of varying height and width. The water then unites in a narrow gorge, which is only 80 meters wide, and rushes madly, with a deafening roar, for about 40 miles before its force is spent, and then Rio Parana calmly rolls on toward the sea. A small Argentine man-of-war went up the Parana as far as the mouth of the Iguassú River, which is several miles below the Guayra Falls, and sailed up the Iguassú River as far as the Iguassú Falls. Hence these rivers are not as impassable as many are inclined to believe. At any rate, fishes can and have passed the Guayra Falls, because I found that the ichthyological fauna which lives in such rivers as the Alto Parana and its affluents is identical above and below the falls.

The Pirapora Falls of the Alto Rio São Francisco have been erroneously stated to be a barrier to the migration of fishes. In fact, the Pirapora Falls are not really falls at all, because during the rainy season they entirely disappear. I fished in their edge during the beginning of the rainy season and found them no barrier to the migration of fishes.

It is interesting to note that "Pirapora" has been derived by some from pira = fish and pora = port, but I found in Paraguay that the Guaranis spell *pora* as *poña* (= beautiful), but pronounce it as *pora;* hence the word would mean "beautiful fishes" and not "fish port." Either of these names might lead one to think that fishes do not pass these falls, but during the dry season Pirapora becomes a veritable fish port, because the fishes wait below the falls for the rise of the river at the beginning of the rainy season in order to go farther up the river to spawn. This movement upstream is well expressed by the Guaranis by the word *piracema* (pira = fish, cema = rising).

Another interesting waterfall is that of Piracicaba, found in Rio Piracicaba in the State of São Paulo. This fall has been a barrier to most species of fishes, but it has not been the absolute barrier that its name indicates (pira = fish, cicaba = ends). During *Piracema* the Indians, in their exaggerating way, say that the fishes pile up so deep below the waterfalls distant from civilization that one can walk across the rivers on the backs of the big fishes, and that their wriggling about produces a roar like thunder. Even though this is extremely exaggerated, there is a certain element of truth in it.

In order not to swamp the reader with too much detail, I will directly draw my general conclusion concerning waterfalls, because I have already described the important types of fall and because the remainder of the falls have been described with varying degrees of accuracy by numerous other travelers and explorers. Before drawing these conclusions, it is worth noting that whenever the height of a waterfall is given, it is the maximum distance between the water levels above and below the falls, and not the height of side channels and series of "tumbles" which often furnish ready passages for fishes and other aquatic forms.

Practically none of the many hundred waterfalls existing in the central and lower courses of Rio Parana and its affluents, Rios Tieté. Grande, Paranaponema, Ivahy and Tibagy, Rio Uruguay, Rio Tocantins, Rio Xingú, Rio Tapajos, Rio Madeira, Rio Negro and other South American rivers have been barriers to the migration of the fishes, which either spawn in the upper courses of the rivers or live in such environments. The only absolute exception to this conclusion is the Iguassú Falls, which have already been considered.

The Giral, Theothono, Guaja Mirim and the other 27 Madeira-Mamoré falls, Esperanca of Rio Beni, Alcoboça and numerous other falls of Rio Tocantins, Forto Principe da Beira of Rio Guaporé, Avanhandava and Itapura of Rio Tieté, Salto Grande da Paranaponema of Rio Paranaponema, Urubupunga and Dorado of Alto Rio Parana, Itaituba of Rio Tapajos, etc., are typical examples of such falls, the general location of which are shown on Bartholomew's New Commercial Map of South America.

In the headwaters of practically all of the highland rivers flowing into either the Amazon or the La Plata, there exist and have existed in some part of their courses many very high waterfalls which are now, and their ancient locations far away from their present sites have been since the early Mesozoic epoch, effective barriers to the migration of all aquatic forms, excepting the common highland fauna, which is always very poor in species. These falls are even now, after ages of erosion, often 400 or more feet high and are nearly always perpendicular. Their volume of water is small and no possible side channels exist. The Kaieteur Falls in Guiana, Salto de Rio dos Patos in Parana, Brazil, the fall in Rio Santa Rita from Serra da Agoaphey and the fall in Rio Juruena of Rio Tapajos are typical examples of such falls.

Between the waterfalls of the central and lower courses of the rivers and the waterfalls in their headwaters, as well as below the waterfalls in the central and lower courses of the rivers and along the Atlantic coast of South America, are many extensive swamps which have been produced in various ways. It is these swamps which are responsible for a common erroneous opinion that the most of South America consists of swampy sultry lowlands which are beladen with every bad thing that exists. Even though these swamps are not as extensive as they are generally considered to be, they are nevertheless of profound significance, especially in the study of environment and the distribution of aquatic forms, and therefore we will next consider the mode of origin of these swamps, which may be roughly divided into two classes, as follows:

1. The coastal swamps, which have been formed by the comparatively recent slight rise of the coast, followed by an unequal deposition of sediment both by the rivers and by the production of sand-dunes. This is true for the Lagoa dos Patos of Rio Grande do Sul, as well as for the various other coastal swamps like those of Iguape and at the mouth of Rio Doce. There appears to be little or no doubt that the swamps of at least part of the Gran Chaco of Argentina and southwestern Paraguay, as well as those at the mouth of the Amazon and Orinoco, have had a similar origin.

2. In contrast to the above type of swamps are those along the central and upper courses of Rio Paraguay, known as Pantanals, and Rio Amazonas and all of its highland affluents, as well as all the swamps along the

bases of the remains of the Plano Alto. These swamps are entirely due to unequal erosion and a consequent deposition of sediment at different levels, and this has been assisted by the growth of a dense flora and changes in the channels of the rivers. The Concepcion Lake of Bolivia and the Uberava Lake of Rio Paraguay and a countless number of other lakes which are found within the limits of the Plano Alto (cf. Plate XII) belong to this class of swamps. The swamps in the central courses of the rivers are usually due to changes in their channels.

During the rainy season, all of these swamps become flooded, and consequently it takes about a month of heavy rains to start a large flood in the lower courses of the rivers. It also takes three or four months of the dry seasons before the water can percolate through the swampy vegetation and get into the channels of the rivers.

The location and heights of the waterfalls, the location and kind of swamps and the kinds of environment are directly associated with the geological structure and the altitudes. Inasmuch as I have already briefly considered the geology, the altitudes may be profitably considered at this point.

The highest point in Brazil is Pico de Itatiaya (2804 meters), which is between the states of Rio de Janeiro and Minas Geraes. The highest point in Guiana is 2621 meters. The highest point in the Cordoba Sierra is 2530 meters. A few peaks of the Andes surpass 20,000 feet, and Aconcagua is over 22,000 feet high. The Plano Alto is seldom over 1000 meters, but one point in Goyaz is said to be 1500 meters above sea level. In Rio Grande do Sul, parts of the eroded Plano Alto are often not more than 300 meters above sea level.

The divides formed by these higher elevations are, as has been previously stated, correlated with the natural conditions of the descending rivers. Therefore, the following brief list of altitudes along the more important rivers has been given, not only on account of the above reason, but also because the abundance and the distribution of all plants and animals are confined between more or less definite positive and negative altitudes of the land and the sea.

Place	Altitude above sea level
São Antonnio, last fall in Rio Madeira	96 meters
Guaja Mirim, first large fall in Rio Mamoré	208 "
Jatoba, above the Paulo Affonso Falls	246 "
Alto do Serra, near São Paulo	837 "
Rio Tieté, near São Paulo . . about	750 "
Jalapão, headwaters of Rio Sapão . . about	600 "
Mouth of Rio Jaurú in Rio Paraguay	153 "
São Carlos, on Rio Negro above Manaos	247 "
Villa de Matto-Grosso, on Rio Guaporé . . about	300 "

The above brief list of altitudes is sufficient to show

1. That the upper courses of the highland rivers are at least 150 meters and usually more than 200 meters above sea level. In the upper courses, I do not include the headwaters which naturally correspond more or less with the altitudes of the divides. In this list, it is important to note that Rio Paraguay has about the same altitudes as Rio Amazonas and stands in marked contrast with that of the Alto Rio Parana and its affluents like Rio Tieté.

2. That the headwaters are rarely less than 300 meters and on the average are about 900 meters above sea level.

3. That the middle and lower courses of the rivers are usually less than 200 meters and on an average are 100 meters above the sea level. The main stem of the Amazon and La Plata rivers are exceptions to this rule, because their middle courses are only about 100 feet above sea level.

The marked differences in altitude, which are more or less associated with the direction of the wind, the temperature, the amount and time of rainfall, the geological structure and all the other factors which compose an environment, separate South America into several distinct faunal and floral regions, even though most of it is generally considered to be tropical.

Space will not permit a detailed consideration of the composition of faunal regions, but perhaps the following rough analogy will make the idea clear. When the naturalist who is familiar with the United States thinks of the regions near Tampa, New Orleans, New York, Chicago, Flagstaff and San Francisco, he can easily distinguish any one of the regions from the others in various ways. In like manner, the naturalist who is familiar with South America can at once distinguish any one of the following regions from the others: The Pampas, the Campos, the Plano Alto, Patagonia, Gran Chacos, Mattos Grossos, the Secca or arid regions of Brazil and the Cordillera de los Andes.

In brief, when I think of Patagonia, I think of a region covered with calafate bushes, low, level or rolling, scanty rainfall, temperate climate, and a region characterized by a general paucity of life, but not a desert. When I think of Pampas, I think of a deep, rich alluvial soil, whose grassy surface is as level as a floor and in many ways is like an Illinois prairie which never freezes. When I think of the Plano Alto and Campos, I think of more or less elevated sandy plains which are covered with scanty highland grasses, an occasional scrubby tree, sparkling water, few pests and a delightful climate. When I think of Chacos, I think of swamp palms, *Lepidosiren,* cutting grasses, floating treacherous grassy surfaces, decaying plants, foul odors, sultry atmosphere and alligators. When I think of the vast Secca country of northeastern Brazil, I think of little or no rainfall, cactus, spiny and thorny plants and scrubby trees, dead insects, starving animals, hot dry air, and a gray dead appearance of everything excepting the sun, moon and stars.

When I think of Mattos Grosses, I think of forests and jungles which are composed of an amazing number of kinds of plants all mixed up, loaded with vines and orchids and harboring monkeys, parrots, sloths, armadillos, humming birds, insects and other animals galore. In other words, a region where life is at its present climax, a region where the conditions for the existence and evolution of life are most favorable.

In like manner, we can arrange the rivers of South America into a few groups in which the sum total of the natural conditions are almost identical, excepting the volume of water. These groups of environmental complexes are shown on Plate XV and are as follows:

1. In the Campos of the State of Rio Grande do Sul and Uruguay is Rio Uruguay on one side and Rio Grande do Sul on the other side of the divide.
2. Rio Parana and its affluents, Rio Tieté, Rio Grande and Rio Paranaponema with their cool, clear water rushing over many waterfalls, are on the west slope of Serra do Mar, and Rio Ribeira de Iguape, Rio Parahyba and Rio Doce on the east side of the same sierra.
3. The northern part of Rio São Francisco belongs to the "secca" region, which includes the most of Rio Parahyba do Norte; the western part belongs to the highland region, which is also embraced by the Amazon, and the southern part of Rio São Francisco belongs to the region of Alto Rio Parana.
4. The Amazon is so diverse that it includes several smaller regions; and Rio Essequibo and perhaps Rio Orinoco on one side and the Alto Rio Paraguay on the other side belong to the Amazonian realm in reference to the sum total of their natural conditions.
5. The Patagonian and the West Andean rivers each belong to quite distinct natural regions. Perhaps the Patagonian should include the southern portion of the West Andean, *i. e.*, Chile.

The profound importance of a clear conception of these regions will, I hope, become more evident in the last part of this thesis.[23]

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[23] It is well known that the environment produces changes in both the individual and the species. When these changes are produced in the germplasm, they are transmitted to the offspring. Is it not to be expected then that at least some of the offspring from the same species of plants and animals would become different after the parent species arrived in the different environments? And may it not also be expected that at least some of the offspring from the same species under identical external conditions, even if widely separated, will evolve some identical species?

OUTLINE MAP OF SOUTH AMERICA

Showing environmental complexes in which the sum total of the natural conditions are about equal

PART II. DISTRIBUTION OF THE SOUTH AMERICAN FISHES AND ITS BEARING UPON ALLEGED CONNECTIONS BETWEEN SOUTH AMERICA AND THE EASTERN HEMISPHERE

DISTRIBUTION OF THE FISHES

Introduction

In attempting to explain the distribution of South American fishes, I have been handicapped by lack of data bearing upon

(*a*) The question whether all of the species concerned are real species. Experimental work is entirely lacking which would demonstrate whether the species are real, composed of several elementary species, varieties or only individual and local variations (ontogenetic species of Jordan) which have responded to different external conditions, *i. e.,* affecting the somaplasm and not the germplasm.

(*b*) The nature of the ancestral species. That is to say, which species of a given genus is the nearest to the ancestral one that became widely distributed.

(*c*) Actual ancestral form. Fossils are exceptionably rare and fragmentary.

If I followed the old static method, not only such data but also the changes wrought by the environment would almost be neglected. In this case, it would be relatively easy to compile the exact localities of all of the species in a given family, and by comparing the long list so obtained, divide the world into as many faunal regions as these data would warrant.

In strong contrast to this older method used by the most of the writers on geographical distribution of South American animals is the study on *Leptinotarsa* by Tower.[24] I cannot improve on his statement (p. 52) concerning the two viewpoints of geographical distribution, which is as follows:

> "The geographical distribution of animals, or animal geography, is usually considered from one of two viewpoints, the static or the dynamic. Considered from the static standpoint, the facts of distribution are taken and arranged according to some empirically chosen standard, and zones, sub-zones or other unnatural areas of distribution are established. The study of animal distribution from this standpoint is a dead and profitless pursuit. Dynamically considered, animal geography seeks to explain the facts of animal distribution as we now find them in terms of the relation of the animals to each other and to their environmental complexes."

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[24] W. L. TOWER: "An Investigation of Evolution in Chrysomelid Beetles of the Genus Leptinotarsa." Carnegie Inst. of Washington. 1906.

In so far as possible, it is the dynamic aspect of the distribution of the South American fishes that I shall consider in the following pages.

On page 9 of the same remarkable book, Tower states the following ten criteria which have been used by Adams, Allen and others to determine the center of origin of a fauna when no fossils are known:

1. Location of the greatest differentiation of a type.
2. Location of dominance or greatest abundance of individuals.
3. Location of synthetic or closely related forms.
4. Location of maximum size of individuals.
5. Location of greatest stability and productiveness in crops.
6. Continuity and convergence of lines of dispersal.
7. Location of least dependence upon a restricted habitat.
8. Continuity and directiveness of individual variation or modifications radiating from the center of origin along the highways of dispersal.
9. Direction indicated by biogeographical affinities.
10. Direction indicated by animal migration in birds.

After critically considering the above ten criteria, Tower[25] states that the following four are adequate for determining the centers of origin or adaptive radiation, without the introduction of any of doubtful value:

1. Location of greatest differentiation of a type.
2. Continuity and convergence of lines of dispersal.
3. Location of synthetic or closely related forms.
4. In some cases, location of dominance or great abundance of individuals.

I quite agree with Tower that these criteria are sufficient to determine the point of origin, if the four criteria themselves can be correctly determined, and I believe that these four criteria can be correctly determined in a given genus like *Leptinotarsa,* but when the genus becomes very widely distributed, with many distinct species and varieties, it is more difficult, if not impossible, to determine these four criteria. At any rate, they cannot be correctly determined for the families and orders of animals without the aid of fossils, because the factors and conditions become so complicated that the determination would be nothing more than an opinion of the individual. For example, I have been able to show that certain species in a certain genus of Cichlidæ have evolved from another species, but which of the many species in a widely distributed genus is the ancestral one cannot be easily and correctly determined. Furthermore, even though we are able to determine that one particular genus of the twenty odd genera of the cichlids is the most primitive and that most

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[25] *Op. cit.,* p. 13.

of the genera are found in the Amazon valley, we have yet absolutely no evidence that the ancestral Cichlidæ originated in the Amazon. In fact, as Matthew has already pointed out, the presence of a large number of species in a given locality is no evidence as to their point of family origin. Indeed, neither the genus nor the family need have originated there, since, as Matthew has shown, the point of origin is apt to be the first place of extinction. We may note, therefore, that the above rules which have been used to determine the point of origin of any group of animals have only a limited application.

So far, there have been only a few specialists interested in the ichthyology of South America. Of these, Professor Eigenmann has certainly given us the best treatise on the distribution of the fishes. In fact, his publications are the only ones which deal in a comprehensive way with the great mass of these fishes, including as they do almost two thousand species.

In the problems of the origin and dispersal of Cichlidæ and Characinidæ, Professor Eigenmann (1906) has given interesting data. He has prepared a hypothetical map which indicates that the Cichlidæ dispersed from eastern Guiana and the Characinidæ from the Amazon. This conclusion appears to be based on the fact that the most of the genera of Cichlidæ and Characinidæ are found in these regions. As I have already stated, however, this is no evidence for the point of origin and subsequent dispersal of a family of animals. If it is, we might erroneously conclude from the present distribution that the deer and tapir originated in the state of Matto Grosso, Brazil, and the camel in the Andes, because more of the species are found there; but in these latter cases, paleontology has shown that the first point of origin was in the northern hemisphere, where the species no longer exist. I hope to show in the following pages that the point of origin of many species and genera of living Cichlidæ has been in the Amazon, but that the point of origin of the ancestral Cichlidæ was not in South America.

In another paper, Professor Eigenmann draws the following conclusions in his extended discussion of the distribution of the South American fishes:

1. The fishes of South America exhibit no close affinity with those of North America.

2. The South American fishes, certainly the Characinidæ and Cichlidæ, lend support to the Archhelenis theory.

3. The fishes of the coastwise streams of eastern Brazil differ more widely from the Amazonian than do the Paraguayan.

4. The distribution of the fishes indicates that South America was

divided into a northern and a southern part, *i. e.*, Archiplata and Archamazonia of von Ihering, and a connection appears to have existed between Guiana and Africa.

There may be little reason to question the data of Professor Eigenmann, but there is, I believe, much reason to question his interpretations. The first conclusion, we believe, is to be accepted for the living affinities of the South American fishes, but when we are dealing with their points of family origin, we are in most cases concerned with ancestral forms which have been dead for geological ages. In this case, the fossil record, scanty though it be, shows affinities between the living South American and the fossil North American fishes.[25a]

Conclusion number two is also questionable, because:

1. There is no geological support for the Archhelenis theory. This is all the more true for the late Cretaceous, when the Cichlidæ probably originated.

2. The point of origin and dispersal of the Cichlidæ, as I propose to show in the following pages, was not correctly determined.

In the matter of his third conclusion, it should be said in Professor Eigenmann's behalf that he did not then know that the Paraguay was not connected with the Guaporé and that the São Francisco was connected with the Tocantins. He also did not know which waterfalls were not barriers for fishes and that both the coastwise streams and the Alto Rio Parana have more than double the number of species which he assigned to them.

In the same report, Professor Eigenmann also states that, of the number of species of fishes, 60 per cent of the Guianan, 40 per cent of the São Franciscan, 53 per cent of the Paraguayan, 30 per cent of the coastwise streams of eastern Brazil, 42 per cent of Trinidad and 6 per cent of Central American are Amazonian. In this static comparison, he has introduced a probable source of error due to the environments when he draws conclusions from the above data. His lists include the fishes from the entire basins of the coastwise streams, including Rio São Francisco, the entire Amazon basin and only the central and upper Paraguay River, which is only one of the affluents of the great La Plata basin. If we compare the massive Amazon with the entire basin of the coastwise streams, is it not necessary to compare the entire La Plata basin and not only one part, *i. e.*, only one environmental complex? For example, if we should compare the fishes from Rio Sapão of the Rio São Francisco with those of the mighty Amazon and its affluents, 100 per cent would be Amazonian,

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[25a] See H. F. Osborn: "The Age of Mammals." New York. 1910.

and hence it would be more like the Amazonian than are the Paraguayan; but in this case we would compare only one environmental complex which is duplicated in the enormous Amazon Valley. (In cases like Central America, the zoögeographer is concerned more with the ancestral distributed form than with the recent cenogenic modifications of them due to the environment.)

In the same lists, we find 122 species for the lower Parana, only 64 of which, or 52 per cent, are Paraguayan. If this could be true, then the Paraguayan fishes are more like the Amazonian than the Paranean. This, of course, is to a certain degree quite absurd, because small ocean steamers can sail up the La Plata into the central course of either Rio Paraguay or Rio Parana. In this case, according to the old view, fishes would, in the first place, have to find their way overland from the Amazon Valley to the Paraguay (a distance of about 200 miles separating the typical fauna of the two basins), and then, for some unknown reason, remain in the Alto Rio Paraguay and not venture to swim down the Paraguay into the Parana.

Professor Eigenmann also states that the Alto Rio Parana had only 31 species, but I have often collected more than this in a single day. I collected more than 100 species in the region of the Alto Rio Parana and its affluents, and there is no reason to believe that the list was then exhausted.

The point brought out in the above brief review is that far too little is known about the fishes or any other South American fauna to prove any hypothesis by a numerical comparison of the species found in diverse regions.

If, for example, we add *Cichlasoma bimaculatum* and *Crenicichla lepidota* to the São Franciscan fauna and *Gymnotus carapo*, etc., to the coastwise streams, and if we compare the entire river basin, there can be no doubt that some of the faunal regions, and especially the cause of the differences in their fauna as explained by Professor Eigenmann, do not agree with the actual facts.

The alleged support derived from the fishes for an Archiplata, Archiguiana and Archamazonia needs no discussion, because the geological evidence shows that no post-Paleozoic seas have invaded the Plano Alto. In the case of Patagonia, there have always been two possible connections with the Plano Alto, one by the Cordova and the other by the Archean rocks of the Andean region. Inasmuch as the invasions of the sea were usually north and south, there is no evidence that southern South America was completely isolated for a long period from the rest of South America by an arm of the sea.[26]

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[26] See PILSBRY, 1911.

Use of Characters

The problem of defining the characters or the kind of characters which distinguish species, genera, etc., has never been satisfactorily solved. The writer will venture to consider only that part of it which concerns the distribution of South American fishes.

In the main, there are two schools of ichthyologists, the American and the English. The American school makes many divisions of the families, genera and in some cases the species. The English school has, as a rule, been more conservative with taxonomic divisions and has therefore fewer but larger groups. In support of the American school may be given the results of the excellent experimental evidence obtained by de Vries, Tower, Johannsen and others, which indicate that the systematic species is a complex one. In other words, this experimental evidence tends to split up the species of the systematist into several elementary species. Much can be said in favor of this finer analysis of species from the experimental standpoint, but little can be said in favor of it from the standpoint of the systematist, because he does not know whether his specimens are hybrids, whether they have a wide range of fluctuating variation, whether they are mutations or whether the peculiarities of the observed somatic differences are inherited or not.

Therefore, from the standpoint of geographical distribution, it appears that the English system, with its fewer divisions and divisions based on more than single characters, is the better one, at least until we have analyzed our species experimentally.

In reference to what characters are important from the standpoint of the fish geography of South America, we are exceedingly fortunate, at least in the case of *Priscacara*, a fossil cichlid described by Cope from the Eocene of Green River, Wyoming.[27]

From this interesting genus and from a comparative study of the South American Cichlidæ, we are able to state with a high degree of certainty that the ancestral Cichlidæ had the following characters: Three anal spines; short gill rakers; more than one row of short conical teeth in each jaw; pharyngeal teeth; ctenoid scales; serrated preoperculum; a continuous spiny and rayed dorsal with more than eight spines; single naris or a tendency for narial coalescence; a rather short, deep body, and a tendency to form a two-parted lateral line.[28]

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[27] I have examined some of Cope's types and believe that Woodward and Pellegrin are correct in considering *Priscacara* a fossil cichlid.

[28] It must be granted that it is difficult, if not impossible, to decide in the case of all of the characters of fossil and living forms which characters are paleotelic and which are cenotelic, but we can agree on at least a sufficient number to show that no living cichlid fish could have given rise to those of both Africa and South America.

These, then, were actually some of the characters of the primitive Cichlidæ of the eastern and western hemispheres.

These ancestral, primitive or phylogenetic characters may be designated paleotelic, a term which has already been used in a similar sense by Gregory in his book on the orders of mammals.

In contrast to these paleotelic cichlid characters are the four to thirteen anal spines of *Cichlasoma* and other genera, the long gill rakers of *Chætobranchus* and *Chætobranchopsis,* the lobe on the upper branch of the first gill arch of *Geophagus* and *Heterogramma,* the long teeth of *Ptenia,* the chisel or incisor teeth of *Uraru,* the long and more slender body of *Crenicichla,* etc. These recent, adaptive or physiological characters may be designated cenotelic. There is no evidence that any of these cenotelic characters have been distributed anywhere excepting in South and Central America, because it is these and other characters which distinguish the Cichlidæ of the western hemisphere from those of the eastern.

I cannot overemphasize the importance of paleotelic and cenotelic characters, because many zoölogists and paleontologists have not made any distinction between these two types of characters in their tabulated comparisons of various faunal regions. In the case of cichlid fishes, cenotelic characters have evidently to do with the origin and dispersal of variation, species, etc., while paleotelic characters deal with the ancestral fauna which gave rise to these genera. The paleotelic characters have to do with the ancient distribution, hence theories like Archhelenis; while the cenotelic have to do with the present distribution of a given genus. The cenotelic characters are usually modified by the action of the environment on the ancestral forms of a given genus, while the paleotelic characters in part have extended down through all of the genera of the cichlid family. Therefore, from the standpoint of the origin and lines of dispersal of the Cichlidæ, a few paleotelic characters will outweigh a bookful of cenotelic ones.

What shall we learn, then, by a careful compilation of all of the Cichlidæ of South America and Africa and by comparing all of those found in one river basin with those found in another? Would this show that a connection had existed between certain points of Africa and South America? Or would it merely be a compilation of cenotelic characters formed by the action of the environments of the different localities on the ancestral Cichlidæ which possessed paleotelic and not the recent cenotelic or secondary characters?

From the standpoint of the origin of the ancestral Cichlidæ, then, the living species or the specific characters alone give us no clue, because they are based on cenotelic characters. The generic characters are often no better, because they, too, are usually cenotelic.

Take, for example, the genus *Cichlasoma*, which is primarily distinguished by the presence of four to thirteen anal spines from the genus *Æquidens*, which has only three anal spines. For all we know, a mutation with four anal spines could have easily appeared from the three anal forms, or *vice versa*. In fact, that is exactly what seems to be the case in Rio São Francisco, where I found only two specimens with three anal spines among thousands of the four-anal-spine form, *Cichlasoma bimaculatum*. In southern Brazil, I found just the opposite, namely, only three four-anal-spine forms of the same size, color, etc., as thousands of three-anal-spine forms which are known as *Æquidens portalegrensis*. Hence all such closely drawn genera must be used with great care in the determination of the point of family origin and dispersal, because they are based on such characters that a mutation or individual or local variation might readily establish a new genus and species in a very short time.

The importance of having a clear idea of the exact status of the ichthyological taxonomy, and especially the value of generic and specific character and which are paleotelic and which are cenotelic, are of prime importance in the explanation of the distribution of the fishes. For example, the writer described *Geophagus brasiliensis iporangensis* as a new variety from the headwaters of Rio Ribeira de Iguape. This variety may be a distinct species, and it may be only a somatic change due to the environment. The adult forms certainly look and measure like a distinct species, but I observed that the young individuals, one and two inches long, could not be told from the lowland young of *Geophagus brasiliensis*. It is highly probable that this new variety would produce typical *Geophagus brasiliensis*, if it were removed to the lower course of the same river. The same may be true of *Crenicichla iguassuensis*, also described by me from the Rio Iguassú. This species is closely related to *C. lacustris* and would perhaps produce that species, if subjected to the same external conditions. These two examples illustrate the present status of South American ichthyology. One can, I believe, readily separate out a couple of hundred forms of the two thousand catalogued for South America which are probably not species, but merely "ontogenetic species," showing, for example, somatic changes of a color spot, a few more or less scales and spines or some other trivial physiological difference. Many of these species, in fact, are based on single characters, such as teeth, which are variable structures. The same have been shown experimentally with birds, beetles, butterflies, etc., living in different temperatures, etc., and until the fishes are better and experimentally known, their present static distribution offers only hypothetical evidence of the shakiest kind for any theory.

Ichthyological Faunal Regions

In the first part of this thesis, the writer briefly outlined the principal environmental complexes in which the sum total of the natural conditions was about equal in each complex. In the following pages, I propose to analyze the changes which have been wrought by the environments on the distribution of the fishes; but before making the analysis, it is first necessary to consider the range of the fishes.

The Siluridæ are found everywhere in South America. The Cichlidæ and Characinidæ are found everywhere north of Patagonia and east of the Andes. A few Characinidæ and Cichlidæ are found on the western slope of the Andes of Peru and Central America, and a few are also found in the West Indies. Two species of Characinidæ are also found in northern Patagonia.

The few species found in the West Indies diminish in number of genera the farther the islands are from the mainland There is thus a suggestion that the Cichlidæ and Characinidæ came directly from South America by way of the sea. I have no doubt that this is true, since by actual experiment I have determined that certain of these genera will live for some time in sea water.

The Characinidæ have never been completely revised, and consequently the genera cannot be of equal value. Notwithstanding this lack of revision, the following summary of the genera is instructive. Of the 129 genera of Characinidæ which have been described, 94 are found in the Amazon Valley, 50 are widely distributed, 60 are found in the Paraguay, 64 in the Guianas, 58 in the Orinoco, 54 in the La Plata, 41 in the São Francisco and 37 in the coastwise streams of southeastern Brazil. The Paraguay harbors about 60 genera of Characinidæ, 58 of which are found in the Amazon. The species belonging to these genera are not usually as similar as are the genera, for example, of the 118 species of Characinidæ reported by Eigenmann from the Paraguay, only 63 are found in the Amazon, while 45 of his 47 Paraguayan genera are found in the Amazon. Do the above data indicate a direct connection between the Paraguay and the Amazon? No, and for the following reasons:

1. There is at the present day no connection and no indication of an ancient connection, at least since the present ichthyological fauna has developed, at such an altitude as to be favorable for lowland forms to cross from one basin into the other.

2. No connection is known to exist between the rivers of Guiana and

the Amazon, and yet there is as great, if not greater, identity of fishes there than in the case of the Paraguay.

3. There are connections between the Orinoco and the Amazon and the São Francisco, and yet there is less similarity between their faunas than between these of the Paraguay, Guiana and the Amazon.

The key to the explanation of the distribution of the characinids lies in the 50 genera which are not only widely distributed, more or less cosmopolitan, but the more generalized members of their families. The same is also strongly indicated by the fact that when these widely distributed generalized genera arrived in the different environmental complexes, there resulted less conformity between the species than between the genera and a greater similarity between the species which lived in similar environments, even though they are not connected, than between the species in dissimilar environments which are connected.

I have already shown that the Plano Alto separates the La Plata basin from the Amazon. This being the case, we have to look for another explanation of the distribution of the fishes other than river connections. The most natural way to seek the explanation is first to consider the fishes which live on the Plano Alto.

I have found the following genera on the Brazilian highlands (a maximum list):

Siluridæ:

Callichthys, *Pydidium*, *Rhamdia*, *Pimelodus*, *Pimeladella*, *Plecostomus*, *Doras*, *Trachycorystcs*, *Auchenipterus*, *Heleogenes*, *Loricaria*, *Hoplosternum* and *Corydoras*.

Characinidæ:

Erythrinus, *Hoplias*, *Holerythrinus*, *Characidium*, *Creatochanes*, *Pœcilurichthys*, *Acestorhynchus*, *Curimatus*, *Moenkhausia*, *Astynax*, *Tetragonopterus*, *Phyrrhulina*, *Pœcilocharax*, *Serrasalmo* and *Chalcinus*.

Cichlidæ:

Geophagus, *Crenicichla*, *Æquidens*, *Cichlasoma* and in two places *Heretogramma*.

Rivulus, *Symbranchus marmoratus*, *Hypopomus brevirostris*, *Gymnotus carapo*, *Eigenmannia virescens* and *Sternopygus macrurus*.

All of the above genera are not only widely distributed but also the most generalized types of their sub-families. They are represented in the highlands proper by only a few species. For example, I found only twenty-five species in the highlands of Parana above the big Iguassu Falls. The following is the list which I collected in the highlands of northern Goyaz:

Hoplias malabricus, Bloch.
Acestorhynchus falcatus, Bloch.
Hoplerythrinus unitæniatus, Spix.
Characidium fasciatum, Reinhardt.
Curimatus elegans, Steindachner.
Creatochanes sp.?
Moenkhausia oligolepsis (?) Gunther.
Astaynax bimaculatus, Linnæus.
Crenicichla lepidota, Heckel.
Cichlasoma bimaculatum, Linnæus.

A similar paucity of species has been noted by Eigenmann in the highlands of Guiana. He has kindly given me the following list which he collected above the Kaieteur Falls:

Rhamdia quelens
Heleogenes marmoratus
Pydidium guianense
Callichthys callichthys
Lithogenes villosus
Corymbophanes andersoni
Phyrruhlina filamentosa
Pœcilocharax bovalli
Moenkhausia oligolepis
Moenkhausia brownii
Creatochanes affinis
Pœcilurichthys bimaculatus
Astyanax mutator
Hoplias malabricus
Hoplerythrinus unitæniatus
Erythrinus erythrinus
Gymnotus carapo
Hypopomus brevirostris
Rivulus holmiæ
Æquidens potarensis
Heterogramma ortmanni
Crenicichla alta

It is at once evident from the above that there have never been found more than twenty-five species in any one locality on the Plano Alto. Compiling the possible lists from various localities, however, we might obtain as many as fifty species as inhabitants of the Plano Alto. If we even doubled this probable list, there would still be about fifty species, many belonging to lowland genera common to the Paraguay and Amazon valleys, to account for in some other way than by a possible overland passage. Hence other factors than mere land-bridges, river connections, etc., are involved in the present distribution of South American fishes.

It has already been stated that the highland genera, usually small in size and widely distributed, are the generalized types which have produced the bulk of the ichthyological fauna. In fact, the highland genera which I have enumerated include 33 per cent of the 1917 species which have been reported from South and Central America by Eigenmann. The highland genera of Cichlidæ include 150 of the 187 species of Cichlidæ reported by Eigenmann from South and Central America.

The above statistics are sufficient to show that most of the purely freshwater fishes are directly related to the highland genera which continue to enter practically all of the rivers north of Patagonia and east of the Andes. None of these highland genera need a direct connection between the river basins, because they are found not only above high waterfalls which have been barriers, but also in all of the river basins, some of which are distinctly separated. In this connection, I may note that I saw young *Hoplias* swimming during a heavy rain in a trail over the highlands of northern Goyaz fully two miles away from the nearest rill.

I have already stated that the highland genera directly account for the distribution of at least 33 per cent of the entire ichthyological fauna without the necessity of direct connections between the different river basins. Neither river connections nor the existing highland genera, however, will account directly for all of the species in common between any of the rivers; nor will they explain the more difficult question why so many of the common species have remained identical in river basins which may or may not be connected. In order to answer this most difficult question, I have chosen the cichlid fishes, because they are the best known of any large family of South American animals.

In brief, the question is, Why are there more species of Cichlidæ in common in Guiana, the Paraguay and the Amazon than in the Parana, Uruguay, the coastwise streams of southeastern Brazil and the Amazon? The following list gives the genera of Cichlidæ and their distribution. Those marked with an asterisk (*) have few species and are more closely drawn than the others. The word "general" means everywhere north of Patagonia and east of the Andes.

* *Chætobranchus*, Amazon to North,
* *Chætobranchopsis*, Amazon and Paraguay,
* *Cichla*, Amazon to north, Orinoco and Guiana,
* *Uraru*, Guiana and Amazon,
* *Herotilapia*, Lake Managua,
* *Neetroplus*, eastern slopes of Mexico and Central America,
* *Acaropsis*, Amazon, Guiana and Orinoco,
* *Petenia*, Lake Peten,
* *Tomocichla*, Costa Rico,
Herichthys, Texas to Guatemala,
* *Astronotus*, Paraguay, Amazon and Orinoco,
* *Xannacara*, Essequibo,
Æquidens, general and western Ecuador,
Thorichthys, eastern slopes of Mexico and Central America,
Cichlasoma, general and both slopes of Central America,
Crenicara, Amazon and Guiana,
Crenicichla, general,
* *Retroculus*, Amazon,
Heterogramma, Paraguay, Amazon and Guiana,
Geophagus, general,

* *Symphysodon*, Amazon,
* *Pterophyllum*, Amazon, Guiana and Orinoco,
* *Biotœcus*, Saraca in Amazon,
* *Paraneetroplus*, Rio Sarabia, Mexico.

According to the static viewpoint of animal geography, we should conclude from the above data that the Cichlidæ originated or dispersed from either the central or the northern part of the Amazon Valley, because sixteen of the twenty-three genera are found there. Five other genera are found only in Central America. All of the seven genera which are found south and east of the Amazon basin are found also in Rio Amazonas. Statically, also, we could interpret the entire absence of Cichlidæ from Patagonia as meaning that this group had a more northern origin; but inasmuch as the genus *Æquidens*[29] possesses more of the paleotelic characters of the ancestral Cichlidæ, it is evident from its distribution that it may have originated in many places not embraced by the mighty Amazon. Also the fact that at least eight of the sixteen Amazonian genera are highly specialized, *i. e.*, cenotelic, may be taken as evidence that these forms have evolved in this region from less specialized forms whose center of origin was not necessarily in the Amazon. In fact, the Amazon has only two genera which are not found elsewhere in South America, and both of these genera are closely drawn and contain only one species each. Therefore the above list of genera and all that is known about them offer no conclusive evidence that the majority of the living American Cichlidæ originated in the Amazon. They may equally well have originated, as far as the above evidence shows, in either Guiana, the Orinoco or anywhere on the old Plano Alto. Before attempting to determine the point of origin of the Cichlidæ, I will first put some of the typical genera in their environmental complexes in order to explain their present distribution.

Rio Uruguay and Rio Grande do Sul, Including Part of the Lower La Plata

This complex is characterized by medium to low altitudes, sub-tropical to temperate climates, campos, slow flowing water and little or no forests. This region harbors the following species of Cichlidæ:

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[29] Pellegrin (1904) considers this the most primitive genus, but *Crenicara* also has many paleotelic characters.

Geophagus brasiliensis { *balzanii*, *brachyurus*, *gymnogeyns*,
gymnogeyns,
brachyurus,
balzanii,
Æquidens portalegrensis = *Cichlasoma bimaculatum*, having only one anal spine more,
Cichlasoma facetum,
Crenicichla lepidota, southern form of *C. saxatilis*,
lacustris,
vittata, southern form of *C. macrophthalmus*.

These species are found on both sides of the divide in the State of Rio Grande do Sul. The region is characterized by *Geophagus gymnogeyns* and *brachyurus*.

Alto Parana and Coastwise Streams of Eastern Brazil

This complex is characterized by higher altitudes, numerous waterfalls, rapid water, sub-tropical temperature and forests. It harbors the following species of the Cichlidæ:

Geophagus brasiliensis with two varieties,
Crenicichla lacustris { *C. jaguarensis*, *C. iguassuensis*,
vittata (*C. dorsocellata*, southern form of *C. macrophthalmus*),
lepidota, southern form of *C. saxatilis*,
Cichlasoma facetum (*C. autochthon* and *C. oblongum* being synonymous),
Cichlasoma bimaculatum, northern form of *Æquidens portalegrensis*.

These six species and their varieties are found on both sides of the divides between the headwaters of the Alto Parana and the coastwise rivers of eastern Brazil. This region is characterized by two varieties of *Geophagus brasiliensis*, two varieties of *Crenicichla lacustris* and one variety of *Crenicichla vittata*. Whether these varieties will breed true or whether they exhibit only somatic changes which are not necessarily inherited is not known, but they show, at any rate, changes due to the peculiar environments in which they live. For example, the young of *Geophagus brasiliensis* var. *iporangensis* could not be distinguished from the young of the common form, but the adults were strikingly different. The variety lived in the rushing headwaters of Rio Ribeira and the common form, *G. brasiliensis*, lives more in the lowland sections of the rivers, lagoons and swamps. I observed a similar change from lowland to highland forms near Santos. I also observed that *Geophagus brasiliensis* occasionally is taken from salty water. I put this species directly out of fresh into a bucket full of sea water. It was able to live several hours under these conditions.

São Francisco and the Secca (Dry) Region of Northeastern Brazil

This region is characterized by desert-like flora, no forests, scanty rainfall and occasional long dry seasons during which many rivers become dry. The altitude is medium (246 m. at Jatoba above the Paulo Affonso Falls).

This region harbors the following species of the cichlid fishes:

Cichlosoma bimaculatum,[30]
Crenicichla lepidota,
Geophagus brasiliensis.

It is interesting to note that the above three genera are also the only three which are found in Rio Grande do Sul, where, in place of having the same three primitive species, six new more cenotelic species have evolved from the above three more generalized widely distributed forms. The only explanation is that the environment of the muddy semi-arid Rio São Francisco has not been conducive to either the production or the maintenance of new species, because the original species were identical for both of these environmental complexes, *i. e.*, they came from the same ancestral highland stock.

The Paraguay as Part of the Amazonian Complex

The great swamps, called pantanals, of the Paraguay are in all respects the exact southern counterpart of part of the Guaporé and the central portion of the Amazon basin. Their similarity must be great, because they all lie in the confines of the central portion of the remains of the Plano Alto. This is not true of either the Parana, Uruguay or São Francisco rivers, as well as the Andean affluents of the Amazon. The similarity is further very striking in altitude, while the Parana is three or four times higher. Inasmuch, however, as the Amazon Valley is so large, it duplicates several times the natural conditions found in the Paraguay as well as in several other rivers. This duplication includes temperature, altitude, food, volume of water, swamps, nature of currents, humidity, rainfall, nature of sediment and muddy and clear water.

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[30] I collected two specimens with three anal spines which were exactly like *Æquidens portalegrensis.*

Given then this duplication of environmental complexes and given also the same common generalized widely distributed genera of Cichlidæ, may we not also expect some similar changes in the common germplasm?

The Paraguay harbors the following species of cichlid fishes:

Chætobranchopsis australis, southern form of *C. orbicularis*,
Astronotus ocellata,
Æquidens paraguayensis, southern form of *A. teteramerus*,
    portalegrensis, southern form of *Cichlasoma bimaculatum*,
    dorsigera,
Cichlasoma festivum,
Crenicichla simoni, perhaps synonymous with *C. reticulata*,
    semifasciata, perhaps synonymous with *C. cyanonotus*,
    lepidota, southern form of *C. saxatilis*,
    vittata, southern form of *C. macrophthalmus*,
Heterogramma tæniatum,
    trifasciatum,
    borelli, giving off *H. ritense*,
    corumbæ,
Geophagus balzanii,
    jurupari.

Of the sixteen species of Cichlidæ, only five are found in Rio Uruguay and Rio Grande do Sul, only three are found in Rio São Francisco and only three are found in the Alto Rio Parana and the coastwise streams of southeastern Brazil. These three are widely distributed species. All of these sixteen species excepting five are also found in the Amazon, and of these five, two are *Heterogramma*, which are connected by intermediate stages in such a way that *Heterogramma tæniatum* can easily give rise to all the species of this genus. Two of the other species which are not found in the Amazon are *Crenicichla semifasciata* and *simoni*, but these are still questionable species, and they also may even exist in the Amazon. In order to explain this identity of the Cichlidæ, I might even grant that all of these species have in some unknown way interchanged between the Amazon basin and the Paraguay. If, however, I should grant so much as that, I should then find even greater trouble in explaining not only why the rest of the Cichlidæ of the Guaporé were not able to get in the Paraguay, but also why the Paraguayan species have remained identical with those of the Amazon and why the Paraguayan species have not invaded the Rio Parana and Rio Uruguay, all of which have navigable channels in their lower courses. In other words, the La Plata basin has a triple cichlid fauna, and these correspond exactly with the natural environments of the Alto Parana and the coastwise streams of eastern Brazil, Rio Uruguay and Rio Grande do Sul, and Rio Paraguay The changes wrought by these environments on the more generalized highland genera is adequate, I believe, to account for the present distribution of the Cichlidæ, but this does not explain their point of origin.

Before taking up this latter subject, it is necessary to produce further evidence showing that it is the action of the environmental complexes on widely distributed genera which has produced the present distribution of the South American fishes and not direct river connections or intermingling of species and isolation.

Rio Amazonas Region

The following is a list of the Cichlidæ of Rio Amazonas:[31]

Chœtobranchus flavescens, Guaporé,
    semifasciata,
Chœtobranchopsis orbicularis,
Cichla temensis, Orinoco,
    ocellaris, Orinoco, Guiana, Guaporé,
Uraru amphiacanthoides,
Acaropsis nassa, Guaporé,
Astronotus ocellaris, Guiana, Orinoco,
    orbiculatus,
Æquidens teteramerus, Essequibo, Guaporé,
    vittata, Colombia, Guiana,
    paraguayensis, Guaporé,
    subocularis, Guiana,
    portalegrensis, Guaporé,
    dorsigera, Guaporé,
    duopunctata,
    zamorensis,
    guaporensis, Guaporé,
    awani, Guaporé,
Cichlasoma bimaculatum,
    festivum, Guaporé,
    severum, Guiana, Guaporé,
    psittacum, Orinoco,
    spectabile,
    coryphœnoides,
Crenicara altispinosa, Mamoré,
    maculata,
    punctulata, Guiana,

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[31] This list does not exactly agree with my report from the Carnegie Museum, which was slightly changed by Professor Eigenmann. Perhaps some of the omitted species should be added, but I am inclined to believe more should be dropped, even a few described by the writer. In the main, however, this is the most accurate list at hand and is sufficient for its present purpose, including as it does all the genera.

Crenicichla reticulata, Guiana,
cyanonotus,
lepidota, Guaporé,
saxatilis, to the north,
lucius, Guiana,
macropthalmus, Guaporé,
acutirostris,
lenticulata, *Guiana*,
strigata,
cincta,
johanna, Venezuela, Guiana, Guaporé,
lugubris, Venezuela, Guiana, Guaporé,
santeremensis,
Retroculus ladifer,
Heterogramma tæniatum and a variety, Guaporé,
agassizi, Guaporé,
trifasciatum and a variety, Guaporé,
corumbæ, Guaporé,
Geophagus surinamensis, Guaporé,
cupido, Essequibo,
jurupari, Guaporé,
acuticeps.
Biotœcus opercularis,
Symphysodon discus,
Pterophyllum scalare.

It may at first sight appear strange that the Amazon harbors so many species and genera of Cichlidæ, but it is exactly what one would expect because of its vast size and tropical location. Of these fifty-three species, at least twenty-two are found in Rio Guaporé, and of these twenty-two, twelve are not found in the Paraguay. This fact alone is sufficient to disprove any wholesale exchange of fishes between the Paraguay and the Guaporé. From the standpoint of phylogeny, I am able to throw a little light on the above distribution of the Cichlidæ. These conclusions were derived from both the field and laboratory, and inasmuch as the purely systematic data have already been published by Pellegrin, Regan and more recently by myself, I will not repeat them.

1. I consider *Geophagus brasiliensis* as the most primitive of the living members of this genus. It is interesting to note that this species is not found in the Amazon and that its nearest northern ally is *Geophagus steindackneri*, which was originally described by Steindachner as *Geophagus brasiliensis* from Rio Magdalena, which, like the coastwise streams of southeastern Brazil, flows out of Archean mountains and possesses therefore remarkably similar environments.

2. *Æquidens teteramerus* appears to be the most primitive of its genus.

It changes in the Guaporé River into *A. paraguayensis,* which is also closely related to *A. vittata.* All of the species of this genus form a natural group about *A. teteramerus,* excepting *A. portalegrensis,* and I consider it as giving rise (or *vice versa*) to *Cichlasoma bimaculatum.*

3. *Heterogramma tœniatum* can easily give rise to all of the species of this genus. In fact, I have reasons to doubt the reality of all of these species, because they may be nothing more than fluctuating variations, principally in color, or somatic changes which may or may not be inherited. At any rate, there is an almost complete intergradation of all of the species of this genus. Hence experimental work is needed before this genus can be properly classified.

4. There can be no doubt that *Cichlasoma bimaculatum* is the most primitive of its genus, because it is not well defined from *Æquidens portalegrensis,* which is the most primitive living cichlid genus.

5. I consider *Crenicichla saxatilis* as the most primitive of its genus. It is represented in the south by *C. lepidota. C. vittata* is the southern form of *C. macropthalmus,* and they are connected by varieties through *C. lucius* to *saxatilis. C. johanna* and the other elongate Amazonian species of this genus also can be linked to *C. saxatilis.*

I will not venture to discuss the relationship of the other genera and species, because the results would be only an opinion with little or no support. The above brief consideration, however, is extremely useful, because *Cichlasoma bimaculatum, Æquidens teteramerus, Geophagus brasiliensis* and *Crenicichla saxatilis* are the generalized types which not only are widely distributed but also have been the origin of the bulk of the Cichlidæ found in the various environmental complexes. The genus *Cichlasoma* alone, according to Eigenmann, contains eighty-four of the one hundred eighty-seven known species of American Cichlidæ. These four genera actually embrace at least 80 per cent of the species of the American Cichlidæ, and several other genera can easily be derived from them.

These four genera are found from one end of the Plano Alto to the other, and consequently from their present distribution we can explain the origin and distribution of their derivatives, but this has nothing to do with the origin of the cichlid family.

To sum up briefly, then, the distribution of the Cichlidæ, we may say that three highland genera are found in Rio São Francisco and have not evolved any new species. The same three genera have produced nine species in the Rio Grande do Sul, *i. e.,* the three old plus six new species, and six species in the Alto Rio Parana and the coastwise streams of eastern Brazil. Sixty per cent of the Paraguayan Cichlidæ are also included by the same three genera and more than 50 per cent of the Cichlidæ of the Guaporé are not found in the Paraguay.

The diagram forming Plate XVI indicates the evolution and distribution of the cichlid fishes of the Amazon Valley and the rivers south of it. It shows that river connections or interchanging of fauna and barriers or isolation are not the important factors of geographical distribution, but that the organic complex of the ancestral stock (three highland genera—*Geophagus, Crenicichla* and *Æquidens-Cichlasoma*) and the composition of the environmental complexes in which they came to live, produced by the rivers sinking into the Plano Alto, are the important factors. The figure also shows that similar and identical evolution of the common ancestral stock has taken place in similar environments and dissimilar evolution in dissimilar environments regardless of whether the environments are or are not connected. (See Plate XV.[32])

The phylogeny of the extra Amazonian species, *i. e.*, more than thirty-three (fifty-three existing in it), is not yet clear, but they will eventually be deduced from the highland stock, because I have shown that the Amazon Valley as we now know it has existed a comparatively short time.

The facts as shown on the diagram are almost exactly the opposite to what one would expect, if land and water connections or isolation were the important factors of living animal distribution. The numbers at the end of the arrows show the number of new species which have unquestionably descended from the old highland stock when it entered the rivers which were gradually eroded in the Plano Alto. The diagram also shows the basins connected or not and the identity of fauna in disconnected regions, such as Alto Parana and coastal streams. I have no first hand knowledge of the Rio Orinoco; hence I do not discuss it.

Additional proof of similar evolution in similar environmental complexes, even if they are not connected, is offered by the larger species of South American fishes. For the sake of clearness, I have divided a typical abbreviated list of large species of fishes into the following classes:

1. Large species of fishes found in the upper Guaporé and Amazon, and neither the genera nor the species found in the Paraguay-La Plata basin. A few examples of such fishes are *Cichla ocellaris, Phractocephalus hemiliopterus, Brachyplatystoma reticulatum* and *Electrophorus electricus.* To these and many other fishes may be added the large croco-

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[32] Whether we should call these isolated species identical or by the same name may be a debatable question. Not any two individuals are identical, but these species are not at present distinguishable.

OUTLINE MAP OF PART OF SOUTH AMERICA

Showing the centers of evolution and the distribution of the cichlid fishes of the Amazon Valley and the rivers south of it

dilian *Caiman niger*, the large Amazonian turtles *Podocenemis expansa* and *P. tracaxa* and the red porpoise *Inia geoffroyensis*. All of these forms are found as far up Rio Guaporé as Bastos, Rio Alegre. If any direct swamp connections existed, I should certainly expect to find these animals in the Paraguayan pantanals. The smaller species of caiman, *Caiman sclerops*, is found all over South America excepting Patagonia and west of the Andes, but it has been seen six miles away from water, and hence an overland trip is not impossible for it.

2. Large species of fishes found in both the Guaporé-Amazon and the Paraguay-La Plata, but never near their headwaters, *i. e.*, at least fifty miles apart in a straight line between the two basins. A few typical examples of such fishes are *Sorubim lima*, *Hemisorubim platyrhynchus*, *Sciades pictus*, *Mylossoma aureus*, *Charax gibbosus*, the giant *Paulacea jahu* of La Plata and *Paulacea lutkeni* of Amazon (I consider the last two species synonymous). These and at least fifty other species which are found both in the Amazon and the Paraguay have not interchanged as such between these basins, for the following reasons:

1. No connection has existed.

2. They are not found in the headwaters, *i. e.*, above the waterfalls and at such high altitudes as exist between these rivers.

3. The distance between the headwaters is so great that an accidental distribution is not possible.

4. Even if a connection had existed, it would not explain why the species have remained the same and why Rio Uruguay and Parana, belonging to the same river basin as Rio Paraguay, do not possess all of these species but, on the contrary, harbor many species not found in Rio Paraguay. Why, also, did not other species interchange, if a connection has existed?

5. The São Francisco River is connected with the Amazon Valley, yet it does not have nearly as many Amazonian species as does the Paraguay. In fact, its common or Amazonian species are cosmopolitan forms. Rio São Francisco has an unfavorable environment (dry, hot, high, muddy, fewer swamps, etc.) and therefore has fewer species than the large Paraguay, with its favorable cichlid environments which have produced more cenotelic changes in the ancestral stock.

In view of all this, it appears that the only answer which can be given to the question why the Paraguay has at least 53 per cent of Amazonian fishes is

1. About 50 per cent of the similarity is due to the cosmopolitan forms, *i. e.*, to overland distribution of the small generalized highland genera which are widely distributed.

2. When these highland forms arrived in the same kind of environments, they often underwent identical evolution with that which was taking place somewhere in the massive Amazon.

3. The remainder of the similarity is due to marine immigrants.

The first part of this answer needs no further comment, but the second may appear to be absurd, at least to those who are not familiar either with the South American fishes or with the environmental complexes in which these fishes live. The view that the common highland genera of fishes have often undergone identical evolution in similar environments, even if these environments are well separated, is of the same general nature as those given in the following publications.

Bateson has shown in the case of *Cardium edule* of the Aral Sea that, as the sea dried up, isolated basins were formed in which the salinity was greatly increased, and under these conditions the cockles so separated show similar variations under similar conditions. These shells of the cockles in the higher to the lower terraces showed a progressive change in regard to the following features:

(*a*) Shells became much thinner.
(*b*) Shells became highly colored.
(*c*) Size of beaks became reduced.
(*d*) Shells became smaller in size.
(*e*) The grooves between the ribs on the outside appeared on the inside of the shells as ridges with rectangular faces.
(*f*) A great increase in length in proportion to the breadth of the shells.

Are not the changes observed by Bateson as profound as required to make *Cichlasoma bimaculatum* out of *Æquidens portalegrensis*, or *vice versa?* In this case, the loss or gain of one spine makes a different genus and a species. Thus it is with many other genera and species of fishes whose distribution must be explained by identical evolution in similar environments.[33]

MacDougal has obtained nearly all of the mutations observed by de Vries in Holland from *Œnothera lamarckiana* obtained in France, England and Holland and planted in New York. He also obtained one mutant, *O. albida,* from *O. lamarckiana* Nantucket City. Even if *O. lamarckiana* is a hybrid, it makes no difference, for at least part of the common highland stock may also be hybrid.

Tower has shown, both in nature and by experiments with humidity and temperature on *Leptinotarsa,* that he could produce changes both in

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[33] Some of the small differences may be purely somatic, which are not necessarily inherited. Experimental evidence is necessary to settle this point.

the germplasm and somaplasm or in each separately. For example, he was able to increase the temperature in the laboratory at Chicago and obtain forms of the potato beetle which lived in Mexico. Tower's work shows almost beyond a doubt that when the same species of potato beetle lived in different environmental complexes, similar variations were produced in similar environments. This is all that is required to explain the similarity of certain genera and species of fishes which are found in the Paraguay and Amazon, but not in the Parana, Uruguay or the coastwise streams of eastern Brazil. Furthermore, the requirement is not great, because many of the genera and species of fishes are based on one more or less spine, three to ten more or less scales in the lateral line, color and position of spots and other trivial characters which are subject to a wide range of so-called fluctuating variation. In fact, some of these variations may even exist occasionally in the generalized widely distributed highland species from which the bulk of the ichthyological fauna of the various river basins has evolved.

Any one less familiar than the writer with the region in question would not venture to state that identical evolution has taken place on such a large scale in similar environments. As I have already shown, however, no connection exists between the Paraguay and the Amazon. Accidental overland and marine distribution is more absurd than identical evolution from common highland stock, and even if the species got across, we should still have to admit that they have remained almost the same in the case of the Paraguay and the Amazon and have not in the case of the Parana and Uruguay rivers, which belong to the same basin as the Paraguay. To admit the latter is equivalent to admitting either that identical evolution has taken place in the case of many genera and species of fishes, or else to believing in the fixity of species in one locality and not in another. Furthermore, the São Francisco has a connection with the Amazon, and yet its cichlid fauna is composed of the three common highland genera and species only. If a connection is needed to explain the similarity of the Paraguayan fishes with the Amazon, I desire to ask, Why has the Rio São Francisco only three species of cichlids? Why is there a triple cichlid faunal region in the La Plata basin? Why have the Paraguayan species remained identical with the Amazonian? Why did not more of the Cichlidæ of Rio Guaporé enter the Paraguay? My answer to these questions is that similar environments have produced some similar changes in the same germplasm, *i. e.*, the highland genera which are widely distributed,[34] and dissimilar environments have pro-

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[34] This does not at all imply the inheritance of acquired characters, for it can also easily be a direct effect on the eggs, sperms or germplasm.

duced some dissimilar changes. Many of these changes are of such a nature that the species are adapted to live only in certain kinds of environments. The cichlid fishes usually live in swamps, lagoons or lakes, and seldom in rapidly flowing water. In the open channels, the characins would eat them. The Paraguay and the Amazon have many swamps and many cichlid fishes. Alto Rio Parana has few swamps and few cichlids.

The marine immigrants which have entered the rivers and become permanent dwellers of the same have also increased the percentage of similarity between certain rivers more than between others. Typical examples of such fishes are as follows:

1. The fresh-water skates, *Potamotrygon,* two species of which are found both in the Paraguay and the Amazon. We have no evidence that these two species separately left the ocean and became dwellers of these rivers. Other species of the same genus are found only in the Amazon, in the La Plata, the Guiana and the Orinoco. Is it not possible that some of these species are the results of changes invoked in the marine ancestor by their new environments?

2. Two species of Pœciliidæ, *Rivulus* and *Girardinus,* could easily have gone along the coast from the La Plata to the Amazon. They may also have gone overland.

3. *Stoleophorus olidus.*

4. Two species of Sciænidæ belonging to the genus *Pachyurus.*

5. Several catfishes, and even a few of the characinids and cichlids, might have migrated along the coast, but it is out of the question to assume that all of the identical forms in Rio Paraguay and Rio Amazonas did so because they are not found in coastwise streams, Rio Uruguay and Rio Parana.

There is no doubt that the marine immigrants have played an important part in the production of a greater similarity between the fresh-water fishes of certain river basins than others. I found only two marine species of fish in Rio Colorado of Patagonia and at least one hundred are found in the lower Amazon. Even the sawfish (*Pristis*) is sometimes killed as far up the Amazon as Santerem (476 miles).

The volume of water always bears a relation to the number and size of marine immigrants, and this is especially true when there are many islands, many channels, plenty of food, tidal effects and much brackish water.

It is evident, then, that the small rapid coastwise streams of eastern Brazil, Rio Magdalena and Patagonia should have fewer species than either the Amazon or the La Plata, regardless of any hypothetical connection with the eastern hemisphere, for the following reasons:

1. Smaller volume of water, relative higher altitude, excepting parts of Patagonia and strong currents.

2. The original stock, part of which was marine in origin, did not develop into so many species and genera in the restricted environments as it did in the more extensive environments, because the factors active in the evolution and preservation of life were neither as favorable nor as numerous in the restricted environments.

3. Many species are adapted to live in only certain environments. One would not expect, therefore, to find *Lepidosiren* in the Alto Rio Parana, the coastwise streams of eastern Brazil and Patagonia. *Lepidosiren* lives in the vast swamps (chacos and pantanals) of Rio Paraguay and Rio Amazonas.

4. Species of more or less recent marine origin have encountered far greater difficulty in entering small, rapid, rocky, shallow streams with a limited supply of food than large rivers, because marine fishes are used to swimming in the sea and not in rapid rivers and because the change from sea to fresh water is less sudden.

5. Some of these rivers have higher altitudes, and the number of fish always bear a relation to the altitude.

The last of the environmental complexes which needs a further consideration is that of Patagonia. It lies between 40° and 55° south latitude and is characterized by a general paucity of plants and animals, especially tropical forms. Its plains are arid and forestless. Its rivers are not large, because they are for the most part fed by the melting snow on the lofty Andes. A cold Antarctic current flows along the coast, which is devoid of swamps. Besides, vast tracts of Patagonia have been under the sea during part of the Tertiary period. At this time, it is quite possible that nearly all of its fresh-water life was exterminated, and as the land rose again from the sea with the Tertiary elevation of the Andes, the northern portion of it became semi-desert. In part of this region, the rivers flowing down from the Andes dry up on the barren plains. Hence, a southern migration of fishes would have been almost blocked, excepting in the case of the Pygidæ, which are found everywhere in South America.

Notwithstanding all this and the fact that the Patagonian rivers have few marine immigrants, its twenty-six known species of fishes contrast favorably at least in number, either with the secca (dried) regions of Ceara and Pernambuco, Brazil, or with similar latitudes in some parts of the northern hemisphere. It is not at all strange that such tropical species of fishes as *Arapaima, Osteoglossum* and *Electrophorus* are not found in Patagonia, because they are also not found in La Plata; but it is strange that the Pygidæ are found in Patagonia and *Hoplias malabricus* (of the Characinidæ) is not, because I found *Hoplias* to be one of the best overland travelers of all the South American fishes. The absence of *Hoplias* in Patagonia may be due to its being a tropical genus.

The fact that *Geotria* and the *Galaxidæ* are found in the Australian realm is no evidence that Patagonia was connected with the same, because at least one of these forms is known to enter the sea.[35] The absence of *Diplomyste* and Pygidæ from the Antarctic and the Australian realms seems to me to be far more conclusive static evidence that these regions were not continuous than do the presence of *Geotria* and Galaxidæ in these two regions indicate that they were continuous. The latter two genera could have extended their limits of distribution by way of the sea. If a connection existed, Pygidæ, being good overland travelers, would have had a chance to enter the Australian realm. If *Diplomyste* is the most primitive living catfish, it, too, would have had a chance to extend its limits of distribution. Hence, only marine fresh water and no strictly fresh-water species or genera are common to these regions, and I take this as strong evidence against a former connection between Patagonia and the Australian realm. In fact, Patagonia has no Osteoglossidæ, no Dipnoi and other forms found in Australia.

Origin of the South American Fishes

In the Princeton Patagonian report on the fishes, Professor Eigenmann states that fishes probably interchanged before the beginning of the Tertiary epoch between Africa and South America by way of a land-bridge between Guiana and Africa. The following objections can be raised against this hypothetical view:

1. There is no positive evidence that either the Characinidæ or the Cichlidæ as such existed previous to the Tertiary, but I grant the possibility of their existence in late Cretaceous times.
2. All of the known fossil fishes indicate a northern origin of the living tropical fishes.
3. There is no good geological evidence in favor of the connection. The evidence is all biological and paleontological and questionable in kind.

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[35] It is also probable that formerly both of these genera were able to enter the sea. This is all the more true in view of the fact that much of Patagonia was covered by Tertiary sea.

4. The alleged support derived from the distribution of the fishes is derived from the static viewpoint of animal geography. It is also based on several erroneous ideas concerning the topography, geology and environmental complexes.

5. The point of family origin was not correctly determined, because the greater number of species in a given locality is no evidence that it is a center of family origin or dispersal.

In the preceding pages, I have attempted to explain the present distribution of fishes as being primarily due to cenotelic changes produced by different environmental complexes on the ancestral stock. It was also noted that only paleotelic characters were widely distributed. Therefore we must look for the point of family origin at a very remote epoch, when few or none of living Cichlidæ and Characinidæ existed. In other words, the present distribution has little or nothing to do with the point of family origin. This being the case, we have to look for fossils.

We must confess that no absolutely conclusive knowledge derived from either paleontology or any other source exists from which we can definitely determine the point of origin of the cichlid and characinid fishes; but the analogies which can be drawn from the following data taken in connection with the facts which I have already stated appear to give the most plausible explanation, because it is more in harmony with the known geological data.

The distribution of living and extinct Osteoglossidæ is as follows:

	Number of species	Remarks
Phareodus (Leidy)	2	Eocene of Green River, Wyoming, United States of America, and upper Cretaceous of Chico formation of western United States of America.
Brychætus	1	Lower Eocene of England.
Arapaima	1	Amazon and Guiana.
Osteoglossum	3	Amazon to north, East Indies and Australia.
Heterotis	1	Tropical Africa.

Besides these five genera, two more doubtful genera are known from the late Mesozoic of the United States of America and southeastern England. The above data indicate a northern origin for this family of fishes, which now lives only in the tropics and the southern hemisphere.

Diplomystus, a clupeoid, has recently been divided into two genera by Jordan, and at least seven species are known. They are from the following regions:

Eocene—Green River, Wyoming, United States of America.
Upper Cretaceous—Mt. Lebanon, Asia.
Cretaceous—Mediterranean Islands.
Upper Cretaceous—Bahia, Brazil.
Lower Oligocene—Isle of Wight, England.
Upper Cretaceous—Italy.

Living forms closely related to these fossil species are said to exist in Chili and New South Wales.

Priscacara, with seven species from Green River and Bridger Eocene of Wyoming and Utah are so far the only known fossil Cichlidæ.[36] This indicates a northern origin for the Cichlidæ. One genus with three species of fossil Pomacentridæ are known from the upper Eocene and lower Miocene of Italy.

One species of *Perichthys* is known from Tertiary shales of Taubate, Brazil. This genus still lives in Patagonia and Chili.

At least seven genera with forty-three species of fossil Labridæ are known from the lower Eocene to the lower Pliocene of Europe and England and the Eocene and Miocene of New Jersey, United States of America. One tooth attributed to a member of this family is known from the late Tertiary of the Argentine Republic.

About fourteen genera of Cyprinidæ, including about thirty-three fossil species, have been reported from Germany, Bohemia, Sumatra, Java and various parts of western United States of America. These fossil forms range from the Quaternary to lower Miocene (?). Living forms are found all over the world, excepting Australia and South America. The absence of the Cyprinidæ from South America is the most extraordinary fact in the distribution of fishes. They have existed since the Miocene in southwestern Idaho and are now found in Mexico but not in South America. Furthermore, if an Archhelenic land-bridge existed between Africa and Guiana and this was the means of dispersal of Characinidæ and Cichlidæ, why did not the Cyprinidæ also enter South America? *Tetragonopterus avis* and *T. lignitis* (*Eobrycon* Jordan) from Taubate, Brazil, from shales of doubtful late Tertiary age are so far the only definitely known fossil Characinidæ.

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[36] Woodward, 1898, reported a fragment from Taubate as Æquidens (?).

The facts regarding the Siluridæ are as follows:

	Number of species	Remarks
Clarias	1	Lower Pliocene, India; still living in India.
Heterobranchus	1	Lower Pliocene, India; still living in Africa and East Indian Archipelago.
Silurus	(?)	Upper Tertiary of Europe and India; still living in Paleoarctic realm.
Pseudeutropius	1	Tertiary of Sumatra.
Macrones	1	Lower Pliocene of India; existing in Asia.
Rita	1	Lower Pliocene of India; existing in Asia.
Amiurus	2(?)	Lower Miocene of Canada; existing in .North America and China.
(?) *Pimelodus*	1(?)	Late Tertiary (?) of Taubate lignite, Taubate, Brazil, and of Parana River, Argentine Republic; existing in South America east of the Andes and north of Patagonia.
Rhineastes	7(?)	Lower Tertiary, lower Miocene and Bridger Eocene of western United States of America.
Bucklandium	1	Lower Eocene, England.
Aurius	4(?)	Middle Eocene, Belgium. Upper Eocene, England. Oligocene and Middle Oligocene, Germany. Lower Eocene, Copenhagen. Pliocene, India. (?) Tertiary, Taubate, Brazil.
Bagarius	1	Tertiary of Sumatra.

Woodward stated that *Bucklandium diluvii* appeared to be related to *Auchenoglanis,* which still exists in Brazil. *Rhineastes* is the oldest known fossil catfish and appears to be related to *Phractocephalus* of the Pimelodinæ, which lives in the Amazon.

The age of the Taubate shales, found in the deeply eroded Parahyba Valley, is not definitely known, but the surface deposits containing fishes do not appear to be very old (Pliocene), because the three fossil genera of fishes are still living. Jordan's generic distinction of *Eobrycon* does not appear to the writer to be well founded, because the species of both *Astynax* and *Tetragonopterus* vary considerably in shape. The two fossil species from Taubate may, in fact, fall into the genus *Astynax* as now defined by Eigenmann.

If the writer is correct in considering the Taubate shales as late Tertiary, it is evident from the above list of fossils that the South American as well as the African fishes have evolved from forms which earlier lived in the northern hemisphere. In fact, Osborn has already stated in "The Age of Mammals" that the South American fishes show an ancient northern affinity. The dipnoans and crossopterygians, which are now found only in the southern hemisphere, also were northern in origin, as far as we now know.

The fact that South America has many species but few families of fishes also vaguely indicates a northern origin, because both plants and animals often rapidly break up into new species when placed in new environments. If the Cichlidæ were not northern in origin, how were they able to get into Wyoming during the early Eocene, when they are now not able to get north of Rio Grande and have never been able to enter Patagonia? The mere fact that the characinids and cichlids are still "going wild" in making species indicates that they entered South America during or after the late Miocene, *i. e.*, after South America became permanently connected with North America. This view seems to be all the more probable, because it appears to be easier for animals to move from temperate regions to the tropics than *vice versa.*

It must also be noted, before dismissing the subject of the point of origin of the South American fresh-water fishes, that there is some vague evidence in favor of the marine distribution of at least the Cichlidæ and Osteoglossidæ. The genus *Priscacara* is closely related to the marine Pomacentridæ, according to Cope, and the formation in which they are found appears to have been near the sea level. Hence, in view of the fact that the actual paleotelic or ancestral forms which were distributed are not definitely known, a marine distribution of many primitive forms is not at all impossible. Such a view is made all the more probable by actual experiment as already noted.

The present distribution of the osteoglossidæ can be explained most easily by considering them as northern in origin, at least if the zoögeographers do not entirely ignore the paleontological evidence. It must be admitted that there is no positive evidence to show that the Characinidæ are directly northern in origin, but the only positive evidence at present known indicates that both the Cyprinidæ and Nematognathi, the nearest relatives of the Characinidæ, originated in the northern hemisphere, and it is highly probable that the ancestral Ostariophysi were also northern in origin—if we admit that the Ostariophysi are a homogeneous group. In this connection, the Nematognathi appear to have first split off from the ancestral Ostariophysi. Then the Cyprinidæ split off, and some of the later Ostariophysi were pushed, after the Miocene times, into South America, and the Characinidæ, now found in the southern hemisphere, appear to be the lineal descendants of this ostariophysian stock and have therefore retained more of the primitive characters than either the Nematognathi or the Cyprinidæ.

There have been sufficient connections between North America and South America and between Eurasia and Africa to permit exchange of fishes during past epochs. Besides, many fishes and other fresh-water forms may have been able to migrate short distances along the coast or from island to near-by islands. Hence no objections can be raised against such migrations for want of land connections.

Summary of the most Important Data which have been used to support the View that South America and the Eastern Hemisphere were Primitively connected.

INVERTEBRATES

Crustacea

Ortmann has stated that only one family of crabs found in northern South America lends positive support to his view of Archhelenis, *i. e.*, a pre-Tertiary connection between Guiana and Africa. This family, Potomocarcininæ, are found only as far south as Guiana. They are found in Central America. Why have they not immigrated into the Amazon Valley and south? For all we know, they may have immigrated from the northern hemisphere and have only reached Guiana.

Their ancestral stock might have been drifted across the Atlantic by the African-West Indian current or their ancestral stock, which was distributed, may easily have been distributed by the way of Europe and North America. This is especially true in view of the fact that no identical forms are found in Africa and South America. What was this paleotelic form which became distributed and gave rise to the different genera of the eastern and western hemispheres, and where did it originate? This family of crabs offers a splendid analogy to the present distribution of camels and tapirs which now live in the tropics, but which were originally found in the northern hemisphere. Besides, the Mesozoic forms of crustacea are very imperfectly known, and this is especially true of the crabs in question.

Mollusca

The writer found a bivalve, *Diplodon,* in the Iguassú River above the big falls, which in some form or other appears to date back to the Triassic. This does not necessarily mean that *Diplodon* dates directly back to the Trias, because this genus is widely distributed over the highlands, but it does mean that it is a primitive form. In contrast to the abov genus is *Hyria,* which was seen by the writer only in the lower Amazon and therefore probably does not belong to the older highland stock. I did not see a dozen species of bivalves in Rio Guaporé, which probably indicates a rather primitive stock, but they were very abundant in Rio Uruguay, which indicates a great cenogenic evolution in this region.

In a general way, the mollusca follow the same rules of distribution as the fishes, but our knowledge, especially from accurate field data, of the fresh-water bivalves of South America is entirely too meager to be used in support of any theory. For example, Ortmann has found that some of the bivalves have palpi, arrangement of gills and siphonal openings like some of the African bivalves, but this may be due in both cases to living in muddy, tropical water. Before such evidence can safely be used to support any theory, much careful field work and experimental evidence is needed. That is to say, we need dynamic and not static data.

Many of the fossil bivalve shells in North America resemble living forms in South America. Inasmuch as the soft parts are not preserved, it will be very difficult to determine the paleotelic forms of bivalves which were distributed. Von Ihering has listed 581 species of mollusca along the coast of Brazil, 54 of which are known on both the Antillean and African coasts, while 72 are found in common on the African and Brazilian coasts. He does not appear to attach much importance to larval distribution of these forms, but it is well known that some larval crustacea and mollusca are found on the high seas. Marine turtles also cross the sea. Nichols has recently reported a case in which he thinks that the mid-ocean whirlpool and side currents swept young *Trachurus* from the coast of England to the coast of Florida. These ocean currents are well known to the sailors, who often go far out of a direct route in order to avoid them. In some places, when the winds are favorable, the one off the Barbados Islands is said to run about five miles per hour. Currents, therefore, may have transferred some mollusca between the South American and African coast along with sea weeds and other drift. Then, again, a few forms could have been transferred by primitive sailing vessels between the various ports.

It is interesting to note in this connection that practically all of the mollusca known from the Brazilian coast are reported from near larger or smaller seaports. In other words, very little of the Brazilian coast has been surveyed, and until regions remote from seaports are carefully studied, too much stress must not be laid on the present list of mollusca. Besides, the above lists of common forms on the African and Brazilian coasts include such widely distributed (cosmopolitan) forms as *Mytilus,* which could easily have gone south from the European and North American coasts. The writer looked carefully along the coast south of Iguape for *Aporrhais pespelecani* and was unable to find this form either living or dead. The few dead shells of this species known from a seaport have little significance, because peddlers and sailors are known to be great distributers of shells. The writer picked up one valve of *Lucina jamaicensis* (?) on a sand bar below the Urubu-punga waterfalls of the Alto Rio Parana, which is several hundred miles from the seacoast, but this shell had evidently been dropped there by an Indian.

A very important factor in the distribution of the marine mollusca of the Atlantic Ocean is the tropical condition which existed in the North Atlantic during the Eocene. This would have given excellent opportunities for exchanges of forms between the African-European and American coasts. These ancestors of the existing forms would have been pushed south again when the climate of the North Atlantic became cooler. As a result of this, many resistant ancestral forms living in similar environments and evolving along rather definite lines would produce a great similarity between the coasts of the South Atlantic.

Furthermore, it is not impossible that some young forms of land gastropods could have been carried with tropical plants to the eastern hemisphere just as *Litorina litorea* has probably been imported in some way to the American coast.

After a long detailed study of the living and fossil Tertiary mollusca, von Ihering has recently concluded that Archhelenis, the land-bridge between Africa and South America, began to disappear in the Cretaceous but continued to exist in the Tertiary. Ortmann (1910) used the same data and arrived at a different conclusion, namely, that Archhelenis had disappeared before the beginning of the Tertiary; but neither of these authors has taken into consideration the effects of similar tropical environmental complexes along the African and South American coasts on the ancestral stock from which the existing species have evolved. When this is done and the cosmopolitan forms are eliminated and when due allowance is given possible larval and adult distribution by ocean currents, floating debris and boats, then no land-bridges are needed to explain the distribution of marine mollusca.

Only static studies have been made, and until some dynamic work has been done the evidence derived from the mollusca is not a safe peg to hang a theory on.[37]

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[37] The brachiopoda appear to me to offer even less evidence, because many almost cosmopolitan genera have existed during various past ages. This is all the more true when certain similar forms are known to exist in similar environments. So it appears that extensive land-bridges like Archhelenis will have to rest on evidence derived from geology and continental faunas and floras.

Recently Pilsbry has given an excellent static treatise of the distribution of non-marine mollusca of South America. He has combatted the separation of Guiana, Brazil and Patagonia during past times. In this far, I agree with his conclusions, but his data do not alone warrant them, because the highland environments in Guiana and Brazil are very much alike, and hence similar forms are to be expected from a common older stock, even if these regions had been isolated from each other during part of the Mesozoic and Tertiary times. His static evidence certainly almost if not completely destroys that of Ortmann for a Guiano-African connection, but he has unfortunately located his Brazilian-South African connection exactly in the region where we have given extremely strong geological evidence against such a view. The entire coast of Brazil in this region is fringed by marine Cretaceous, which alone would force this connection to have disappeared at least in the early Cretaceous. Besides, the "Pernambucan fan" is strong evidence against any Paleozoic connection in this region. There is also so much other geological evidence against the building up of a land-mass across the great ocean depths of the South Atlantic that we may consider Dr. Pilsbry's view highly improbable, at least until some dynamic and more careful field studies have been made on the non-marine mollusca of the regions in question. His actual paleotelic forms which were distributed are not yet absolutely known to have originated in this purely hypothetical Gondwana Land.

Ants

Von Ihering has even used the distribution of the ants to prop up his Archhelenis theory. He states that we still see the ingression of Bolivian ants into Brazil. These ants are supposed to have come by the way of Antarctica from the eastern hemisphere. This evidence appears to me to be of little weight, because the ants have had a highland since the Permian, over which they could have crawled or flown into Brazil. Furthermore, practically nothing is known of the ants which live in the highlands of central Matto Grosso. If one may hazard a guess, I would suggest that a detailed study of the ants would show an invasion from Brazil toward the Andes and not *vice versa,* after the elevation of the mountains in Tertiary times.

Corals

Gregory has shown that the Miocene corals of the Mediterranean resemble the living corals of the West Indies. This is not, I believe, evidence that the West Indies were directly connected with the eastern hemisphere, because the larvæ of these corals may have drifted over by the mid-Atlantic whirlpool and ocean currents. They may have originally migrated down the North American coast from Europe, and it is even more probable that the observed affinities are due to similar evolution in similar environments. If this is not true, why have so many species remained similar to the Miocene forms of Europe ever since the supposed land-bridge disappeared or from before Tertiary times? When and where did this bridge exist? Are not the corals of the North and South American coasts also similar? If not, why not?[38]

GONDWANA FLORA

Similar deposits of sandstones, clays, shales and bowlder till are found in Brazil, South Africa, India and Australia. These deposits are chiefly Permian and contain among other fossils the characteristic lower Gondwana flora (*Gangamopteris* or *Glossopteris* flora). The identity of the *Gangamopteris* flora, along with many fossil and living genetically related animals found in Africa and South America, has led to a widely accepted belief that these continents were originally connected. This old land-mass has been designated Gondwana and is thought by some to have extended across the Atlantic between either Brazil or Guiana and Africa. Others have ignored this connection and have maintained a southern connection by way of the Antarctic Islands.

The *Gangamopteris* flora, according to I. C. White and David White, has been found six meters above the crystalline floor of the coal fields of southern Brazil. At this level, only *Gangamopteris obovata* was found. The next higher level, 55 meters above the granite floor near Minas, Santa Catharina, contains *Rosellinites gangamopteridis, Hysterites brasiliensis, Phyllotheca griesbachi, P. mulleriana, Glossopteris browniana, Vertebraria ....?..., Gangamopteris obovata, Arberia minasica, Derbyella aurita, Noeggerathiopsis hislopi, Cardiocarpon seixas* and *Cardiocarpon moreiranum.*

These species belong to the early typical *Gangamopteris* or lower Gondwana flora. The same genera, and in many cases identical species, are found in the Ecca shales of South Africa, in the coal associated with marine lower Permian of New South Wales and Tasmania and in the Karharbari beds of India. The same flora is found in the lower Coal Measures of Argentina and the Falkland Islands. Only much later, in the upper Permian of the northern part of Russia, are any of these

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[38] If Archhelenis existed, I fail to see how the rivers could have been arranged on it so that only one family of crabs, two families of fishes and a few fresh-water and land mollusca took advantage of it, when the same theory assumes that the coastwise streams of eastern Brazil have been barriers to at least part of this fauna.

gangamopterids known to occur in the northern portion of the northern hemisphere.

Conformably underlying this lower Gondwana flora are the Orleans conglomerates of southern Brazil, which are supposed to be related to the Dwyka conglomerates of South Africa, the Baccas Marsh conglomerates and their equivalents in Australia and Tasmania and the Talchir conglomerates of India. These conglomerates contain some of the evidence for the alleged Permian glaciation of the southern hemisphere.

At 135 meters above the granite, *i. e.*, about 80 meters above the typical lower Gondwana flora, is found the intermingling of this flora with some species of the older northern cosmopolitan flora. In this formation were found *Equisetes calamitinoids, Schizoneura, Sigillaria australia, Sphenopters hastata* (?), *Glossopteris indica, G. ampla, G. occidentalis, Nœggerathiopsis hislopi* and *Cardiocarpon oliveiranum.* The flora is still primarily Gondwana. At a still higher level, 157 meters above the granite floor or 100 meters below the Iraty shales containing *Mesosaurus*, are found more of the northern flora, such as *Lepidodendron perdroanum, Lepidophloios larcinus* and *Sigillaria brardii.* At this level, the lycopods are again preëminent as coal makers.

The *Gangamopteris* flora is very imperfectly known, but what is known indicates almost beyond a doubt that the *Gangamopteris* belong to the southern hemisphere. It is not known from North America and is only known from the late Permian of Russia. The question is, then, Are the known facts concerning the *Gangamopteris* flora indicative of a continuous Gondwana Land somewhere in the southern hemisphere? Before attempting to settle this difficult question, it is necessary to consider the origin and the environmental complexes of this flora.[39]

The *Gangamopteris* flora belongs, as Professor Arber and Dr. White have well shown, almost exclusively to families already known in the cosmopolitan flora. They constitute genera and species more or less bound to their northern relatives, though often differing much in form and aspect. In general, they appear simpler in figure, with a tendency to thickness and rugosity of leaves, and on the whole their general aspect suggests environmental conditions unfavorable to luxuriant growth. This flora suddenly appears in the early Permian well defined from its Carboniferous ancestors, which lived in the northern hemisphere and survived more or less the profound geological changes produced by the for-

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[39] It is barely possible that the lower Gondwana flora of Brazil belongs to a later Permian than now believed, as Professor Branner states in his Geologia Elementar that the intercalated marine deposits containing *Schizodus, Myalina* and *Conocardium* also contain other lamellibranchs also found in the Triassic. If this is found to be the case, then the appearance of this flora in Russia-Siberia may have been as early as in Brazil.

mation of the Brazilian Plano Alto. This cosmopolitan flora continued to exist in the Mesozoic epoch, but the *Gangamopteris* flora, excepting *Glossopteris* and *Schizoneura*, vanished with the close of the Permian. In this remarkable fact, we have, I believe, part of the solution of the *Gangamopteris* flora, *i. e.*, it existed in Brazil only during the formation of the Plano Alto and died out after this was completed (early Triassic).

In this profound change of the ancient Brazilian topography produced by the formation of the Plano Alto in the Permian inland basin, we have the production of unfavorable environments which might have produced the alleged glacial effects on the *Gangamopteris* flora and have caused the absence of the cosmopolitan plants in the lower Gondwana formation of Brazil. This view is further strengthened by the fact that the shales, etc., of the lower Gondwana formation have a different appearance and chemical analysis from those of the higher formations in which the cosmopolitan flora are found. The cosmopolitan flora is always associated with the production of large coal fields, and such conditions are not met in the Gondwana formations of Brazil. It appears to me that it was desiccation (perhaps not due to a lack of rainfall, but to its disappearance in a sandy soil) and the blowing of sand into the Permian inland basin, and not severity of climate (glacial), which produced the stunted appearance of the early Gondwana flora.

Several other objections can be raised against the use of Permian glaciation as a factor which affected the distribution of the Permian plants and reptiles of South America. In the first place, the writer does not believe that the existence of glaciers in Brazil has been definitely established. His experience with glaciation in North America and glaciers in the Andes, taken in connection with observations on erosion in the highlands and mountains of Brazil, has strongly suggested to him that the Orleans conglomerates were not deposited by glaciers. In the highlands of Piauhy and various places in Brazil, one can see both highland streams and extensive slanting surfaces over which gravel and bowlders slide during heavy rains. The underlying surfaces and bowlders are often scratched in a way which resembles glaciation. When pieces of the scratched and polished surfaces are detached, segregated or not, as is often the case due to less and greater amount of rainfall, and deposited at a lower level, a "false moraine" and even false bowlder till is formed. When such a mass of gravel, clay, bowlders, etc., becomes covered up and pressed together by later erosion in little stratified or unstratified beds (due to continual deposition and plasticity of the clay), it can easily be mistaken for a glacial deposit. It can only be distinguished from glacial deposits by means of truly faceted bowlders; and inasmuch as faceted bowlders are not definitely known to exist in Brazil, I take this as a strong evidence against Permian glaciation in Brazil. In fact, not until recently has any one even seen striation in the alleged glacial deposits of the Permian of Brazil. Some of these recent false signs of glaciation in Brazil, as Branner has shown, even deceived Agassiz (the expounder of glaciation), who described vast sections of Brazil as being glaciated.

The direction of the striations and the arrangement of the bowlders also offer no conclusive evidence in favor of glaciation. When "false moraine," composed of scratched surfaces, bowlders and false tillite, became covered up by the Permian sandstone found in the Plana Alto, only those deposits and scratches pointing in the direction of the dip of the country were exposed by the post-Permian erosion of the overlying strata. In most of the Gondwana formation, this dip is toward the south and west. Hence only here and there are the striæ exposed, and all of them point more or less in the same direction, *i. e.*, they are only seen along deeply eroded river valleys below the waterfalls. Furthermore, these deposits often cover vast regions. For example, the deposits of such erosion would have covered many miles of width for the entire length of the Serra do Mar during the late Carboniferous and early Permian when the climate was favorable for the deposition of false bowlder tillite, which later became overlapped by the Permian sandstone. Later erosion exposes these deposits over a vast area.

Woodworth found striations on bowlders, some of which appeared to have been deposited by ice floating near sea level (as is indicated by intercalated marine deposits in the Rio Negro basin). This floating ice may have come from Permian swamps, where it gathered up bowlders. This mass may have floated toward the sea the following season, scratching the rocky surfaces along the margins of the swamps. In this case, faceted bowlders would probably not have been formed. I acknowledge that Woodworth has also found much other evidence for Permian glaciation in Parana, Brazil, and the evidence is even stronger for it in the eastern hemisphere.[40]

I grant that glaciers may have existed in Brazil during the lower Permian epoch, but in view of the preceding, it appears that faceted bowlders must be found before the evidence in favor of it is sufficient to warrant the use of Permian glaciers as a factor in the distribution of plants and animals. Even if such evidence is found in Brazil, it will probably not be found after the lower Permian, at which time the typical Gondwana flora and reptiles were scarce. Furthermore, if glaciers ex-

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[40] Woodworth had not published his paper on the Permian glaciation in southern Brazil when these notes were prepared.

isted during the lower Permian in Brazil, they may also have been only local glaciers of high altitude, like those existing in the Andes.

Returning again to the fact that the *Gangamopteris* flora only existed during the formation of the Plano Alto, it appears to me that this is positive evidence that its environment, composition and extinction were directly associated with this great transformation of the South American topography. In other words, the Gondwana flora was an arid highland flora.

It is known in marine series in Australia, but it could have been washed there from higher elevations, and the altitude of these sandy highlands was not necessarily great, in view of the fact that stunted plants are found on the Brazilian highlands at comparatively low altitudes. Similar geological transformations also occurred in India, Africa and Australia. Similar deposits of shales, clays, sandstones, coal, etc., occur in these remote regions. The mere fact that all of these regions possessed almost identical environmental complexes, not known to be perfectly duplicated in the northern hemisphere, is one of the most important factors connected with the origin, the distribution and extinction of the *Gangamopteris* flora, regardless of whether these regions were or were not continuous.

It is a remarkable fact that so many identical species and genera belonging to different families of both the *Gangamopteris* and the cosmopolitan flora could exist, unchanged, in such remote regions as India and Brazil during most of the Permian epoch. Little short of orthogenesis or similar evolution in similar environments can account for such data.

I have already shown that the Permian inland basin of South America is almost completely surrounded by higher Archean mountains which have apparently remained almost stationary during part of and since the Permian epoch. This is particularly true of southern Brazil. Therefore, the fact that the Gondwana flora, so widely distributed over the southern hemisphere, was able to enter these various Permian formations over and around higher Archean mountains is evidence that its ancestors were little or not at all affected by barriers. It is true that this flora might have entered the outlets of the basin along the Permian coasts, but if it was a highland flora, it probably did not.

I am unable to conceive how and from where enough of the typical deposits of Gondwana Land could be derived in such a way that a homogeneous environment might have existed between either Africa and South America, or between South America by way of the Antarctic islands and either Africa or Australia. The Gondwana formation of

South America can easily be explained by place erosion of the highland pre-Permian floor, by the erosion of the Serra do Mar and its southern spur, Serra Geral, on the east side of the Permian inland basin, and by similar changes of the Serras de Cordova, San Luis and de la Ventana on the west. All these mountains have a general north and south trend, and there is no evidence of an east-west trend in any of this region. The Gondwana formations of Brazil, Africa and India dip as a whole toward the south and west. This has a ready explanation from the location of the Archean and pre-Permian rock, but there appears to be no explanation showing how these formations could have been a part of a greater continuous homogeneous Gondwana Land. Its flora being only known from this special type of environment, how did it traverse these obvious Gondwana barriers?

Permian and Carboniferous deposits of coal are laid down along the sides of the Andes-Rocky Mountain system which extends into Eurasia and also on the sides of the Appalachian system, and extending through Guiana down the divide along the eastern coast of Brazil. I am not aware of any similar formations extending through the Antarctic islands toward either Australia or Africa. The Antarctic islands appear to bear the same relation to southern South America as do the West Indies to northern South America. They are well separated from both Australia and Africa by great depths of the ocean as well as by many miles of distance. Hence it appears more probable that the Gondwana flora or its ancestral forms would have migrated along lines where the conditions of the environments of Gondwana Land were at least partially duplicated, *i. e.*, where coal was deposited, rather than over about 2,000 or more miles where such conditions probably did not exist.

The fact that the northern Permian plants had many identical species in the southern hemisphere, that there is considerable difference between the Permian reptiles found in Texas and those of South Africa, as well as the fact that the *Gangamopteris* flora is found in the late Permian of Russia, is good evidence that both the cosmopolitan and the *Gangamopteris* flora were resistent forms which (or their ancestral stock) could migrate into remote regions with comparative ease. The presence of *Cardiocarpon, Sphenopteris, Psaronius, Sigillaria* and *Lepidodendron* in both North America and South America, as well as the presence of the Mississippian flora at Cacheuta, Argentina, indicates an exchange of plants between North and South America. Some of these plants (*Lepidodendron*) are not yet positively known in South Africa. The cosmopolitan flora is also known from Europe and other parts of the eastern hemisphere, and it is remarkable that this flora could not only become so widely distributed but could also remain almost identical in the various corners of the earth.

Even if it be granted that a vast homogeneous Gondwana Land entirely covered the southern hemisphere, this alone would not explain why so many species of the typical lower Gondwana flora remained identical during the greater part of the Permian epoch. There is positive evidence from the intercalated Permian of Brazil and other Gondwana formations that these regions were not continuous during the entire Permian epoch, and yet the flora remained identical. Hence there appears to be no need for a ready and wholesale exchange of this flora, because it remained unchanged during the most of the Permian epoch, and therefore any accidental distribution of each genus and for one time only would be adequate. In this connection, it is to be remembered that neither continuous land connections nor barriers nor isolation causes species (unless there are only a few individuals) to evolve new forms or to remain fixed, but the action of the environmental complexes on the ancestral forms, which had a certain composition, and hybridization will change the species. The identity of the *Gangamopteris* flora in such remote parts of the earth as already noted may be due to the action of similar environmental complexes upon the ancestral stock of each group of this flora. It is then even possible, but not probable, that the *Gangamopteris* flora is only an environmentally changed form of the cosmopolitan flora which could not exist as such in the early Gondwana environment. At least the sporaginous members of the cosmopolitan flora could have migrated into the Gondwana environments, if they had been able to thrive under such conditions.

What the direct antecedent types of the different groups of the Gondwana flora were is not definitely known. David White considers that *Nœggerathiopis* is probably of Cordaitalean origin and *Gangamopteris* has a common origin with the neuropterid group of Cycadofilices, to which the genus *Glossopteris* also is related; yet both are far removed from the known antecedent type of the northern hemisphere. What this direct ancestral stock was and where it originated are questions which must be answered before we can definitely hypothesize lines of dispersion.

I have repeatedly pointed out in the case of fishes that direct connections are not necessary for the production of identical species and that the greater number of species in a given region is no evidence that the family originated there. I will repeat here again that the fact that the gangamopterids are found only in the southern hemisphere is not conclusive evidence that their ancestral stock either originated there or that all of the existing Gondwana formations were directly continuous.

The *Gangamopteris* flora was already well defined in the early Permian. It has no close antecedent types in either the northern or the southern hemisphere, but its actual origin must have antedated the oldest formations where it is known to exist. It may well have been these ancestral types (like the highland fishes of Brazil) which were distributed and not each individual species. These antecedent types may have arisen from the northern cosmopolitan flora and later have migrated into the southern hemisphere where this ancestral stock of the different groups underwent similar evolution in the similar environments of the Gondwana Land. This view is supported by the fact that these ancestral forms would not have necessitated a homogeneous environment, because they were more generalized forms.

Two objections may be raised against this view. First, it is conceivable that *Gangamopteris* or various individual genera may have originated independently in different continents or in different parts of the same continent, but the assumption that a flora of characteristic association and unity as the gangamopterid originated in this way is highly improbable. It is not so improbable, however, if we include representative types of each group in the distributed stock and if we grant, as the facts indicate, that identical evolution took place in similar environments.

Secondly, there is no fossil record of the gangamopterids in North America. This objection to either a northern origin or a distribution of the ancestral genera by the way of North America is, I believe, far from being a fatal one. If the progenitors of the gangamopterids passed through North America, the line of migration may have been along the Appalachian system during the Carboniferous epoch, but the line of migration was more probably from eastern Asia by way of Alaska. At that time, the necessary Gondwana environment for the *Gangamopteris* flora may have existed in North America for a brief period. If it did not, we only have to assume that the progenitors of this flora did not necessitate Gondwana environments for a ready distribution. Dr. White has told me that there is a little evidence in favor of a Cordilleran migration, and recent work in the Permian of Texas indicates the same.

The flora would not have required a vast period of time to interchange between Eurasia by way of North America into South America. The chances are that no trace of these typical Gondwana environments or the ancestors of its flora would remain in either the Appalachian or the Cordilleran regions, because they have been leveled to the sea, excepting in small patches, and re-elevated several times since that epoch. If the flora was a highland flora, we now know where to look for it in western North America.

In this connection, great emphasis must be placed on the stability of the Serra do Mar and the surrounding Gondwana formations of southern Brazil when contrasted with the violent geological transformations which the possible regions of migration through North America have undergone. In fact, I firmly believe that no traces of the Gondwana flora would remain in southern Brazil, if this region had undergone the same radical changes as the possible routes of migration through North America.

The mere fact that the *Gangamopteris* flora appeared to live under rather unfavorable conditions in which little coal was deposited is very important. Could not similar Gondwana environments have existed during a brief period in the northern hemisphere, and might not these environments have been obliterated by the post-Permian changes of the North American topography? It appears that the stability of the Plano Alto has saved the Gondwana flora of southern Brazil.

Professor Branner states in his "Geologia Elementar" that marine fossils are found associated with the deposits containing *Stereosternum* in the State of São Paulo. These fossils are all lamellibranchs, which include such Permian genera as *Schizodus, Myalina* and *Conocardium,* and other genera which are equally well considered as Triassic. This is the only known invasion of the sea that entered the Gondwana region of Brazil during the Permian and subsequent periods. Hence the Gondwana of Brazil has been extremely stable. This indicates very great altitudes along the eastern side of South America during the Paleozoic epoch. These great altitudes are needed to build the great Plano Alto and to account for the existing altitude of Serra do Mar after the vast ages of post-Permian erosion.

If the *Gangamopteris* flora entered South America from North America, one may ask why it is not found in northern South America. Whether it came from North America or not, I believe that it existed in northern Brazil, because the Permian inland basin was continuous from southern Brazil to the Guianas. In fact, *Psaronius* has recently been found by Dr. Lisboa at Floriana on Rio Parahyba do Norte. All this part of South America is very imperfectly known and awaits exploration. If the Gondwana flora is later found in northern South America, about 3,000 miles of a northern distribution will be abridged and the remaining distance will not be many times greater than a possible southern one. Hence due allowance must be made not only for the imperfection of the fossil record but also for the lack of sufficient exploration. When this is done, a northern distribution of the Gondwana flora is not altogether impossible.

As an example of the imperfection of the fossil record may be given *Cryptobranchus,* an amphibian, living in Japan and the Mississippi Valley. The only known fossil relative is *Andrias,* Scheuzer's *Homo diluvii testis* of the Miocene of Europe. Its distribution, in a way, is like that required for a northern dispersal of the Gondwana flora. As an example of the imperfection of exploration may be given the two new marine horizons in the Conemaugh series of western Pennsylvania, found by Raymond in a region which has been explored by many geologists. As I have already stated, however, there is little hope of finding the necessary antecedent types of the *Gangamopteris* flora in North America, because the necessary highland deposits which produced this stunted flora have apparently disappeared, or have not yet been found.

The idea of a continuous Gondwana Land has little or no support other than indecisive statistical data derived from the distribution of living and extinct animals and plants. Furthermore, it appears to me that even such a vast amount of indecisive data which admit of a variety of interpretations can never outweigh the fact that the Permian reptiles, the ooze and shark teeth, etc., of the great ocean depths, such as exist between Africa, Australia and the Antarctic islands, the geology of the Brazilian coast, the absence of giant east and west trend lines of South America and the Antarctic islands offer strong positive evidence that a continuous Gondwana Land did not exist. Until this vast array of positive evidence in favor of the persistence of the great ocean depths and the continental shelves has been satisfactorily accounted for, it is just as inconceivable to explain the existence of a continuous Gondwana Land as to conceive either a northern distribution of the *Gangamopteris* flora or that this flora developed orthogenetically from some unknown northern ancestors which evolved from the Devonian cosmopolitan flora. This is all the more true when we have to acknowledge that the actual point of family origin of the *Gangamopteris* flora is unknown.

Before, however, the reader forms an opinion concerning the existence of a continuous Gondwana Land, as is indicated by the distribution of the Gondwana flora, he should consider still two other possible means of distribution of the Permian plants which require no continuous Gondwana Land.

The distribution of the Gondwana flora by strong winds like those which blow dust from the pampas of Argentina to Africa is possible but perhaps not probable. The *Gangamopteris* plants are now generally considered to be seed-bearing, but in most cases no seeds are known; hence wind distribution would be out of the question, unless the seeds were of very light-winged type. Then they might have been blown for some distance, such as might have intervened between South Africa and the nearest Antarctic islands. If any of them were spore-bearing, then wind distribution would be an important factor, as it is in the case of puff-balls and ferns. It is then important to settle definitely whether any or all of the early *Gangamopteris* flora were seed-bearing or sporogenous.

The last possible mode of distribution is by the way of the sea. David White has informed me that some of the seeds may have been able to survive marine drift for some time. He thinks that the migration was by the Antarctic, and if by the way of the sea, it would have been with a minimum interruption by water. He suggests that it would perhaps be better to say that migration was probably by several lands and not by a continuous Gondwana Land. As the facts indicate, however, this flora was a highland flora, and hence few or none of the species could have been distributed in this way unless they lived on low coastal sandy highlands or campos such as exist in parts of Rio Grande do Sul, Brazil.

In conclusion, we may safely say that we do not definitely know where the *Gangamopteris* flora originated, how and which way it dispersed, why it appeared and disappeared in Brazil during the formation of the Plano Alto and why so many species and genera remained almost identical in such remote regions as India and Brazil during most of the Permian epoch.

The distribution of the Permian reptiles, the deep intervening sea, the trend of the Archean mountains, the mode of the formation of the Permian deposits, the location of marine deposits and the evidence in favor of the persistence of the great ocean depths and the continental shelves offer conclusive evidence that no continuous Gondwana Land has existed between South America and the eastern hemisphere, at least since Carboniferous time. Previous to this, it may have existed, but many data are needed to prove that it did.

In view of the fact that the *Gangamopteris* flora once formed did not appear to vary, we have only to explain how it got, one time, into such remote regions as India, Africa and Brazil, because a continuous exchange of the flora would have been unnecessary. Therefore an accidental marine drift of the seeds and the wind, if any were sporogenous, by way of the Antarctic islands are possible means of distribution, but I believe that the distribution of the ancestral stock was along the Asiatic-American "backbone" of the earth and a subsequent similar evolution in similar environments or else orthogenesis of this stock agrees better with the known data relating to geographical distribution.

The widely accepted view of a continuous Gondwana Land has been derived from the static viewpoint of living and extinct animal and plant geography, but it is no longer tenable. The separate portions of the Gondwana Land are, however, more interesting now than ever.

The only places for various past connections which are needed and almost universally accepted are the following:

Southern South America and perhaps the Antarctic islands.

South America and North America by way of Central America and perhaps the West Indies.

North America and Eurasia by the way of Greenland and the North Atlantic, Alaska and Siberia.

Southern Asia and Australia by way of the East Indies.

Eurasia and Africa.[41]

PERMIAN REPTILES

Does the distribution of the Permian reptiles indicate the existence of a connection between Africa and South America?

Only a few specimens of Permian reptiles have been found in South America. *Mesosaurus brasiliensis* is the best known species. It was described by McGregor (1909) from the bituminous shales of Iraty, Parana, Brazil. *Stereosternum tumidum* Cope is a closely related form. It was found in São Paulo and comes from the surface of a thin layer of limestone. Many fragments of it were seen by the writer near Piracicaba at a limestone quarry on the property of the Agricultural School. A few well-characterized marine fossils have occasionally been found in the series of beds in which *Stereosternum* is found. Two more species of *Mesosaurus* are known from the Dwyka beds of South Africa.

Mesosaurus is not a diapsid. Its unique vertebræ and ribs, as well as the absence of scales, webbed feet, dorsal but no lateral temporal fenestra, slender teeth, long snout, etc., separate the genus from all known reptiles. Von Huene (1910) derives it from some unknown Carboniferous cotylosaurian. So far, not even the antecedent type, which gave rise on one hand to *Mesosaurus* and on the other to *Stereosternum*, is known. It is

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[41] It must be granted that of all the evidence in favor of a continuous Gondwana Land, its flora appears to be the best. But in view of the fact that when it was once formed it did not appear to change, we may suggest as a future working basis that this flora offers a special type of orthogenetic development which has been produced from the cosmopolitan older flora by definitely directed changes in the environment during the formation of the highlands where it is found. In Australia, this flora appears to have been the maker of coal during the Permo-Carboniferous. It is also said to be associated with marine drift and glacial deposits. Hence it appears to be a swamp flora in Australia, but the presence of thick beds of coal and glacial drift in the same regions does not appear to harmonize. If this is true, then the Gondwana environments of Brazil and Australia are distinctly different. A continuous Permian and early mesozoic Gondwana land is needed no more than a Tertiary or a recent one. We now know, however, that no Tertiary Gondwana is required to explain the distribution of animals.

highly probable that this antecedent type, and not *Mesosaurus*, was the form which was distributed.

The exponents of the Gondwana theory must assume that *Mesosaurus* originated and died off on the Gondwana continent where its ancestors are not known, and that it necessitated a continuous Gondwana Land when its distribution is used to support a connection between Africa and South America. They must also assume that *Mesosaurus* was the form which was distributed and that *Stereosternum* evolved from it after it arrived in South America. Two objections can be raised against this view which are based on positive evidence. First, the nearest ancestral cotylosaurians known are from the northern hemisphere, and none are known from South America. Hence the positive evidence in one case becomes negative evidence in the other. In other words, the positive evidence is in favor of a northern origin of the ancestral form which gave rise to *Mesosaurus* and *Stereosternum*. Secondly, *Mesosaurus* was a good aquatic reptile and did not need a continuous Gondwana Land in order to get into Africa and South America.

It is evident, then, that the point of origin of the Mesosauria is unknown. We only know the point of extinction of a few individuals of three species of the genus. The genus was already very distinct from other reptiles in the lower Permian, and its ancestral stock could easily have arisen in the northern hemisphere from some unknown cotylosaurian. In fact, Moodie's paper on the Carboniferous air-breathing vertebrates of the United States National Museum indicates that this is probable, because *Isodectes punctulatus* Cope from the Allegheny series and *Sauravus costei* Thevenin from the Carboniferous of France very remotely point back to Microsauria on one hand and to Mesosauria on the other. At any rate, the Mesosauria must have originated before the beginning of the Permian, and the point of origin could have been in the northern hemisphere just as well as in the Gondwana continent. The fact that the Mesosauria are known only from Africa and South America is in favor of the latter view, while the nearest related antecedent types of Carboniferous Cotylosauria are in favor of the former.

Even if we assume that the point of origin of the Mesosauria was in either Africa or South America, their distribution offers absolutely no argument for a connection between these continents, because the Mesosauria were aquatic reptiles, as is shown by their long snout, long needle-like teeth, lack of scales, dorsal position of nares, unique ribs and webbed, paddle-like feet. McGregor's reconstruction of *M. brasiliensis* indicates that it could not have traveled overland, and inasmuch as it appears to me that no river could have flowed from Africa into South America, or *vice versa*, during any past epoch, *Mesosaurus* would have had to enter the sea in order to get into both Africa and South America.

On account of the intercalated marine Permian in the region where *Mesosaurus* is found as well as the underlying limestone containing marine lamellibranchs where *Stereosternum* is found, I am inclined to believe that *Mesosaurus* was at least semi-marine, if not entirely marine. Its needle-like teeth strengthen this view, because they are adapted to eating soft animals, which must have been far more abundant on the surface of the sea than in the shallow Permian swamps of Brazil, which became dried up again and again, at which time *Mesosaurus* would have been pushed down to the coast. There is, then, little or no doubt that *Mesosaurus* could live both in salt and fresh water just as *Manatus*, and originally *Inia*, which are now found in Rio Amazonas. This being the case, it could easily have extended its range across the Atlantic, because it was a good swimmer. It could also have gone by way of the European-American coast or from the nearest Antarctic islands to southern Africa, where the distance would not have been much greater than traversed by the giant tortoises (*Testudo*) or the semi-marine *Iguanidæ* (*Amblyrhynchus cristatus*) of the Galapagos Islands.[42]

The mere fact that only *Mesosaurus*, the best aquatic form, out of sixty-nine genera of Permian and early Triassic reptiles recently enumerated by Broom for South Africa, has been found in South America, is strong evidence that no connection existed between these continents. The absence of this vast array of land reptiles from the corresponding Permian and Triassic deposits of South America is negative evidence, but it appears to me to outweigh the positive evidence of the marine or semi-marine *Mesosaurus*.[43]

Scaphonyx fisheri Woodward from the Triassic of Rio Grande do Sul, Brazil, is another form which has been used to support the idea of a connection between South America and Africa. According to von Huene, the known fragmentary data, which have been derived from vertebræ and foot bones, indicate that *Scaphonyx* is distinct from *Erythrosuchus* of South Africa. He also thinks that both *Scaphonyx* and *Erythrosuchus* are related to several forms found in the Triassic of North America. A form of *Erythrosuchus* is also known from Europe. Here again the ancestral stock, which was widely distributed and gave rise to these genera, is not known. Hence the fact that *Scaphonyx* of Brazil has a related genus in Africa is not evidence that these continents were connected, because it also had related forms in Europe. The great ab-

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[42] I do not believe that the Galapagos Islands were ever connected with South America.

[43] It is to be noted that the region of the Permian deposits of southern Brazil has been inhabited longer than southern Africa, and it is nearly always the natives and not the few scientific explorers who first find strange animals and fossils.

sence of Permian and Triassic South African land reptiles from South America indicates that *Scaphonyx* evolved from some northern ancestor from which Erythrosuchus also descended.

Broom and others have attempted to show that the Permian reptiles of South Africa and Texas are related. There appears to be no doubt that these reptiles are related, but there is still very diverse opinion as to how nearly they are related. In the conclusion of this interesting paper, Broom suggests a possible scheme of distribution of the Permian reptiles. He thinks that it is probable that a Lower Carboniferous land vertebrate fauna existed in northern South America. This primitive vertebrate fauna included among other forms temnospondylous amphibians, primitive cotylosaurians and primitive ancestral pelycosaurs. He presumes that this fauna ultimately migrated on one hand to North America and on the other hand over the Gondwana Land to Africa. In order to obviate the absence of all early Permian reptiles in South Africa excepting *Mesosaurus*, he further presumes that Permian glaciers of Brazil prevented the other primitive reptiles from reaching Africa until middle and late Permian.

The above view is possible, but not probable, because it is based on the following assumptions: (*a*) a continuous Gondwana Land; (*b*) the existence of lower to middle Permian glaciers in the region of the alleged trans-Atlantic Gondwana, and not in region of northern South America, which was with all probability the highest point at that epoch, and (*c*) the existence of primitive Carboniferous reptiles and temnospondylous amphibians which are not known from South America. We conclude, therefore, that there is little or no evidence in favor of the exchange of Permian reptiles between South America and Africa by way of a continuous Gondwana Land.

In view of all this, the only suggestion which appears to agree with the known facts of geology, paleontology and the Permian environmental complexes is that the primitive Carboniferous reptiles, from which the Permian fauna evolved, originated in the northern hemisphere and were pushed south from Eurasia into Africa, where the descendants retained certain primitive characters and evolved along similar lines in such a way that they more or less remotely resemble the descendants from the same primitive stock which lived in Texas. *Mesosaurus* is an aquatic and at least semi-marine form, and does not lend any positive support to a Permian connection between Africa and South America,[44] because

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[44] The distribution of the extinct and living side-necked turtles (Pleurodira) offer another case of the same principle. The pleurodirans are now found only in the southern hemisphere, but they were very abundant in the Cretaceous of the northern hemisphere, where they probably already existed in the Jurassic. The two other groups of "shelled turtles" (Cryptodira and Trionychoidea) also fit into the scheme of a northern origin and distribution of land animals.

none of the typical South African Permian land reptiles have been found in South America.

MAMMALS

Is an Antarctic connection between Patagonia and the Australian realm needed to explain the distribution of any of the South American extinct mammals?

The best evidence which has been used to support the Antarctica theory is derived from the mammals. It is the best evidence, because slow-moving mammals need land connections more than do either flying or aquatic animals and because the Tertiary record of the mammals is fairly well known. There is, however, a great blank in the fossil record in the entire lack of pre-Oligocene mammals of Asia and northern South America.

The absence of pre-Oligocene animals in both Asia and northern South America is either due to imperfection of the fossil record or to the lack of exploration, because the existence of pre-Oligocene mammals in North America, Patagonia and Africa could not be explained unless the mammals entered both Asia and northern South America; for otherwise we must assume the separate origin of mammals in two or three different places. The works of Sclater, Wallace, Lydekker, Matthew, Osborn and others indicate that the most of the orders of mammals directly or indirectly originated in the northern hemisphere, which has embraced the bulk of the land at least during the age of mammals. It is true that South America and Africa have been separate centers of origin of many mammals, but even many of these can be remotely traced back to the northern hemisphere. The presence of primitive mammals in the Triassic of North America and the Jurassic of North America and Europe taken in connection with the geology of Europe is sufficient evidence to show that the pre-Oligocene animals must have existed in both Asia and northern South America. The distribution of mammals, as I see it, involves, unfortunately, exactly the above regions from which we have no fossil evidence. These are transitional regions between the northern and southern hemispheres. Until the known fossil-bearing region of Bahia, Brazil, is examined and until mammalian fossils have been found in the early Eocene of northern South America and southern Asia, the distribution of the Mammalia will never be satisfactorily settled. Nevertheless, on account of its profound geological significance, I think that a brief re-examination of the materials of the distribution of South American mammals should be attempted.

The only support for the Antarctica theory from the standpoint of the Mammalia is derived from the affinities in the common presence of both polyprotodont or carnivorous forms, allied to the existing Tasmanian wolf (*Thylacynus*) and of the small diprodont herbivorous forms (*Cœnolestes*) very remotely allied to the phalangers and other Australian diprotodonts.

The researches of Broom, Gregory, Dieder and others seem to favor the view that *Cœnolestes* is an independent offshoot of the polyprotodont type which was present in the Eocene of North America and the Oligocene of North America and Europe. It is also to be noted that the Patagonian cænolestoids (*Epanorthus* and its allies) show no clear evidence of close relationship with Australian diprotodonts.

There can be no doubt that the sparassodonts are true polyprotodont marsupials, as shown by Sinclair. They also agree with the Tasmanian *Thylacynus* in certain characters which have been assumed to indicate that they belong to the same family. Dr. Matthew, however, is now of the opinion that these few characters have probably arisen independently in the Patagonian and Tasmanian genera by virtue of parallel evolution from primitive didelphids of northern origin.

The Tasmanian and Patagonian genera are the end result of cenotelic evolution. It was not these genera which were widely distributed, because there are none in common. It was their ancestral stock, if they are genetically related, which became widely distributed.

In the case of the cichlid fishes, I have shown that it was not any of the living genera which were distributed into Africa and South America, but it was a primitive form. Could not this ancestral marsupial, from which *Thylacynus* on one hand and the sparassodonts (*Borhyœna*, etc.) on the other evolved, have originated in the northern hemisphere from some primitive northern polyprotodont during the Mesozoic to early Eocene? At any rate, it is not yet known from either Patagonia or Tasmania.

This primitive ancestor could have been pushed out of Asia into Australia and out of North America during the late Cretaceous to early Eocene into South America. Then similar evolution in similar environments would easily account for the rest of the similarity of the Patagonian and Tasmanian Thylacynidæ.

Until it has been definitely shown what this primitive ancestor of the Thylacynidæ was and where it originated, it appears to be useless to reconstruct the surface of the earth from such evidence.

It is interesting to note that the evolution of the South American mammals agrees in a general way with Schuchert's view of the connections which have existed between North and South America. The first connection existed from the late Cretaceous to the early Eocene, and then a separation ensued until the Miocene, after which there has been a permanent connection. It is exactly from the Eocene till the Miocene that South America evolved its typical mammalian fauna, whose last remains are the anteaters, armadillos, cænolests, sloths and a few tropical marsupials. This indicates that the primitive ancestors of these animals along with others entered South America during the Cretaceous to the early Eocene. It was during late Miocene time that the second important change in South American mammalian life took place. This invasion was without doubt from the north. The third wave was also from the north. It was composed of man and his domesticated animals. The replacement of the older fauna by the later invasions is still seen on all hands in different tropical animals, which still retain the old paleotelic northern characters which are, however, more or less masked by the specialized cenotelic characters.[45]

In view of all the preceding, the writer, while still in the field, changed his previous views concerning all of the hypothetical connections between South America and the eastern hemisphere, and he now believes that all of the South American animals originally came from North American stock.

I am also inclined to believe that the evolution of paleotelic characters, especially of families and orders, has taken place faster in the northern than in the southern hemisphere. This is indicated by the fact that many tropical animals are often a few geological ages behind their northern living or extinct relatives. The edentates, monotremes, ratite birds, many South American birds (screamers, seriamos, sun bittern, etc.), the characins, dipnoi, crossopterygians and osteoglossids (fishes), South African secretary bird, note Aardvark (*Orycteropus*), scaly anteaters (*Manis*), tapirs, camels and many marsupials are examples of tropical animals which are a few geological ages behind time. This retarded evolution of paleotelic characters in the southern hemisphere may be due to a greater stability of the vast Plano Alto of South America.

It is not, in my opinion, the stable portions of the earth which have produced the bulk of evolution, but it is the ever-changing regions either by elevation and submergence or tremendous changes produced by erosion, like the recent formation of the Amazon Valley. These violent changes produced in the environmental complexes appear to pull the trigger of evolution. Inasmuch as geology shows that more radical

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[45] In taking this view, I have assumed that Matthew and Gaudry are correct in considering the Patagonian beds to be later than the upper Cretaceous. Roth, however, considers the *Notostylops* beds to be upper Cretaceous, and Ameginho considers them to be still earlier.

changes in the environments, including the climate, have occurred in North America than South America, it appears probable that paleotelic characters evolve faster. This belief may seem absurd, yet if it is only in part true, it has a profound significance in correlation, and especially in determining the exact age of the fossil beds in South America.

If it is true, then older-appearing South American beds are in reality much more recent. At any rate, this impression demands careful study, and especially in the case of the invertebrates.

I believe that the North Polar theory of the origin of land animals expounded by Haacke and in a general way supported by Wortman, Sharff and more recently by Matthew, is the view which agrees best with all of the known facts of geology, paleontology and zoölogy. Rütimeyer, Huxley, von Ihering, Forbes, Ortmann, Hedley, Sinclair, Ameginho, Osborn and others have maintained connections between Australia and Patagonia, but their evidence has been derived almost entirely from the static viewpoint of zoögeography, which, as Tower has well said, is a dead and profitless pursuit. Besides, there never has been a general agreement between any of these authors either in regard to exact position or time of existence of the connection. They have also utterly failed to show how and why just certain animals were able to get across the connection. Why, for example, did not edentates and other early Tertiary mammals of Patagonia also get into Australia? Would not such a connection have had a barrier? Besides, the distance across this south polar continent is not small. They also do not attach much importance to the strong geological evidence against such connections.

The ideal northern marsupial from which we could easily derive both *Thylacynus* and the sparassodonts is not definitely known to exist, but it is also not known in either Patagonia or Tasmania. In fact, I should expect to find it in Asia and northern South America, both of which places are entirely unknown from the standpoint of primitive mammalian paleontology; but even if the necessary ancestor is never found, it will not be the only gap left open in paleontology.

The indecisive evidence used in support of the Antarctica theory does not appear to me to outweigh the fact that neither the deep-sea soundings, the trend lines, the lack of islands, location of Archean rock nor the location of known marine formations even vaguely suggest a Patagonia-Australian connection. Besides, such indecisive biological data are not as weighty as the vast array of data in favor of the persistence of the continents and the great ocean beds, so ably defended by Sir John Murray and others. The deposits in the great ocean depths like those between South America plus the Antarctic islands, Africa and the Australian realm have never been found in the whole geological series of the continental shelves. Also, the great number of shark teeth found in abysmal depths indicate vast time for deposition. Until all such data and the theory of isostacy have been satisfactorily accounted for, it appears to be useless to continue hypothesizing land-bridges. At the present stage of our knowledge, we do not need an Antarctic land-bridge, but we do need both dynamical data and more careful field work in northern South America and southern Asia before we can definitely settle the distribution of mammals.[46]

SUMMARY

We have seen from the location of the Archean and early Paleozoic rocks that about the present outline of South America has always existed and that the lines of weakness and strength in its crust are usually parallel to the coasts. Hence, the invasions of the seas have, in most cases, been in a general southern-northern direction and not east-west. The location of the deposits left by the invasions of the sea has forced us to deny the existence of Archiguiana, Archamazonia and Archiplata as maintained by some of the exponents of the Archhelenis theory.

The outlines of the Plano Alto, which was deposited in a continental Permian inland basin, has been given, and the general dip of its surface, its lack of past Paleozoic marine deposits, location of surrounding Archean mountains and marine sediments and the Tertiary rise of the Andes indicate the reversal of the Amazon during the later half of the Tertiary epoch. The eastward movement of the mouth of Rio Negro and the single channel of the Amazon in region of Obidos, where remains of the Plano Alto approach the river, indicate that this is near the old divide which has been washed away. The unique marine or brackish water fossils of Alto Rio Amazonas apparently lived in an arm of the ocean (East Andean Sea), which probably extended south, lost its connection and finally disappeared with the Tertiary rise of the Andes. It was also suggested from the character of the overlap that no great extension of land to the east of the present coast was needed to form the sediments of the Plano Alto and that great altitudes probably existed in eastern Brazil and Guiana during late Paleozoic times.

The southeastern Brazilian coast appears to be very old and remarkably stable. It apparently never extended more than about 100 miles to the east of its present location. The fringe of upper Cretaceous deposits

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[46] The evidence from the standpoint of the Mammalia for a Tertiary Archhelenis, *i. e.*, a connection between South America and Africa, is given in the "Age of Mammals," which shows that such a connection did not exist.

along its northern portion, the fan-shaped trend lines west of Pernambuco which fade away toward the coast and are roughly comparable to a somewhat analogous condition in the region of La Paz, Bolivia, its recent slight elevation, its lack of numerous islands separated by comparatively shallow sea and its abruptness being primarily due to erosion of Paleozoic and post-Paleozoic land deposits and not to post-Paleozoic faulting, indicate that South America was never connected with the eastern hemisphere. This view is further strengthened by the absence of deep-sea ooze, etc., from the continental shelves and the abundance of sharks' teeth in the great ocean depths which indicate a vast antiquity for the abysmal depths.

We have noted many facts concerning the South American topography, the most interesting of which were the cases of stream piracy existing between Rio Orinoco and Rio Negro, and Rio São Francisco and Rio Tocantins. The Paraguay River is not connected with the Amazon. These facts, taken in connection with waterfalls, altitude, swamp production, erosion and the composition of environmental complexes, have led to some interesting results concerning the distribution of the South American fishes.

Using the cichlid fishes only as the best known family of South American animals, it has been shown that isolation or barriers and intermingling or river connections utterly fail to explain their distribution. It was found that the present distribution of the fishes is correctly explained by the organic complex of the more generalized highland genera (which are small in size and naturally widely distributed because the Plano Alto was formerly a continuous unit) and by the action of the environmental complexes on this stock. In other words, when the common ancestral forms arrived in similar environments, *i. e.*, similar environments were eroded in the Plano Alto, they evolved along similar and identical lines and in different environments along different lines.

When we attempted to determine the point of origin and lines of dispersal of families and orders, it was found to be absolutely necessary to invoke the aid of fossils. In doing this, it was found necessary to use more than single physiological characters and draw a sharp distinction between paleotelic and cenotelic characters. When this was done, the fishes evidently point to a northern origin and not to an African-South American Gondwana origin.

When similar methods were applied to the Permian reptiles, Gondwana flora, mammals and other alleged evidence in favor of connections between South America and the eastern hemisphere, the evidence was not found convincing for a single case. Thus the Permian reptiles, if critically studied, offer evidence against instead of for a continuous Gondwana Land. In fact, all of the alleged evidence has been derived from the static viewpoint of plant and animal geography which has led to many erroneous views of correlation and geology of South America. There was not found a single case in the evidence for a continuous Gondwana of any age or location in which the distributed ancestral form was actually known.

In view of all this, I have been forced to change my former belief in a connection between South America and the eastern hemisphere, because the geological evidence overwhelms the biological hypotheses. The fragmentary positive evidence in a few individual cases may not always indicate that this view is true, but when both positive and negative evidence derived from botany, zoölogy, paleontology and geology is carefully weighed and due allowance is made for the imperfection of exploration and the imperfection of the fossil record, the evidence is decidedly against the hypothetical connections.

I therefore believe that continental forms have originated and dispersed over three great tongues of land which have always extended south from the northern hemisphere. These three great tongues of land have been connected and disconnected from time to time, and it is possible that they were connected at the south pole at some time previous to the Carboniferous epoch, but so far there is little or no evidence for such a view.

There have been from time to time possibilities of plants and animals interchanging between these three tongues of land by way of the northern hemisphere.

In a word, we do not accept the theses of hypothetical land-bridges and invasions of the sea; we fail to appreciate the weight of the evidence in favor of these theses, and we look forward with keen interest to the results of coming years in field work and in dynamical studies especially in the regions of zoödistributional transitions, *i. e.*, Central Asia and northern South America.[47]

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[47] It is in a way extremely unfortunate that so much work is done in regions like Patagonia and southwest United States in order to prove a theory which can only be proven by hunting the deposits in northern South America.

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SEX-LINKED INHERITANCE IN POULTRY

BY

T. H. Morgan and H. D. Goodale

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SEX-LINKED INHERITANCE IN POULTRY

By T. H. Morgan and H. D. Goodale

(Presented before the Academy, 8 April, 1912)

CONTENTS

Introduction

In 1908, W. J. Spillman pointed out that, according to a breeder, when Plymouth Rock females are bred to Langshan males all the females are black and all the males are barred. As far as the evidence went, it seemed to show, as he pointed out, that the case was comparable to that of the moth, *Abraxas*, described by Doncaster and Raynor, and of certain crosses among canaries described by Miss Durham.

With the intention of examining further the report cited by Spillman, and of testing, by further combinations, the offspring of the first generation, we began the following experiments in 1909, using Barred Plymouth Rock and Langshan fowls. We undertook also to extend the experiment by using another breed of barred poultry, the American Dominiques.[1] It is currently stated that Dominiques (but not American Dominiques) occur in the ancestry of Plymouth Rocks. We wished to see whether "sex-limited" or "sex-linked" inheritance is found also in this other race. Plymouth Rock-Langshan crosses have been made by one of us (Goodale) on the experimental farm of Mr. B. B. Horton, to whom we are under many obligations for opportunities to carry on the work. The Dominique-Langshan crosses were made by the other (Morgan) at Woods Hole during the summers of 1910-11. In the meanwhile, Pearl and Surface (1910) have described the results of a cross (and its reciprocal) between Barred Rock and Cornish Game. Goodale (1909, 1910) has given briefly some of the results obtained when Barred Rocks are mated (reciprocally) with Buff Rocks and when Brown Leghorns are mated with White Rocks. Hadley (1910) has called attention to similar results published by Cushman in 1893. Davenport (1906, 1909) has described various crosses to one of which certainly (White Cochin by Tosa) and to the others less clearly may be given the same interpretation that applies to the results described in the other papers mentioned above. These crosses all involve the barring factor. Sex-linked inheritance of other factors in poultry has been noted, not only by several of the above writers, but also by Hagedoorn (1909), Sturtevant (1911) and Bateson and Punnett (1908). To Bateson and Punnett is due the explanation of the phenomena of sex-linked inheritance for poultry. More recently (1911) these authors have published a complete account of the inheritance of a factor derived from Brown Leghorns which affects the patency of the type of pigmentation characteristic of the Silky fowl.

CROSSES BETWEEN PLYMOUTH ROCKS AND LANGSHANS

Description of the Breeds.—For a detailed description of the breeds under consideration, reference must be made to the various standard works on poultry. In this paper, only a very brief statement of the chief characteristics involved in the cross will be given.

The Black Langshans (Plate XVII, figs. 2 and 3, and Plate XVIII, fig. 1) are uniformly black, varying somewhat in brilliancy in different regions of the body. The shanks, too, are dull black; the bottoms of the

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[1] The American Dominique is a younger breed than the Barred Plymouth Rock.

feet are gray. The shanks, moreover, are provided with several rows of feathers, or boot, along the outer edge. The comb is single.

The Barred Plymouth Rocks (Plate XVII, figs. 1 and 4; Plate XVIII, figs. 3, 4, 5, 6) are black and white,[2] the two colors being arranged in alternate bars across the long axis of each feather. The bars vary somewhat in evenness, width and depth of color from individual to individual, and also in different sections of the same bird. Although the American "Standard of Perfection" requires that the two sexes shall be alike in color, the males vary from a darker to a very light color, often appearing very light gray, while the females, though to a less marked extent, vary toward a darker shade. In other words, the breed tends strongly toward a sexual dimorphism of color, with indications of a secondary dimorphism within each sex. The comb is single, and the yellow shanks are free from feathers.

History of the Breeds.—The modern Langshans are the direct descendants of a very old race brought from the interior of China. The Rocks, on the other hand, resulted from a mixture of several races of fowls about forty years ago, which have been gradually brought to a high degree of perfection. The history of the barred character with which we are chiefly concerned is obscure, but evidently it is of very great antiquity, for barred or "cuckoo" birds are to be found in many European countries, Russia included. Brown (1906) states that the plumage of the "Siberian Featherfooted fowl is generally white, whilst others have cuckoo plumage." He notes also that this variety is said to be of ancient lineage. Wright (1902) states that it is probable that the "original Chittagongs, or at least their crossed offspring, were of an 'owl' color as described, probably what we now know as cuckoo or barred." The Chittagongs came from the district of that name in the upper Malay peninsula. An exhaustive search would probably show that barred fowls have been recorded from southeastern Asia.

Source of Breeding Stock Used.—The Langshans came from P. P. Ives of Guilford, Conn. Two of the three Barred Rock males and one of the females were of the well-known Latham strain, but obtained from R. C. Goodale. Four of the barred females were the progeny of the Latham hen by a White Rock male, one was an F_2 from a similar mating, and one was a pure bred female from a Stamford breeder. The White Rock male is known to differ from the barred birds chiefly in the absence of the chromogen factor.

Matings.—In the majority of these matings, the progenies of the individual mothers have not been kept separate. The determinations of the

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[2] Fanciers prefer to speak of both these colors as grayish.

presence or absence of barring, unless otherwise stated, was made on newly hatched chicks, or those of full term which failed to hatch. This method of determination is made possible by the presence of a gray occipital spot on those chicks which will become barred adults. A full discussion of the point, however, will be given elsewhere. Inroads of vermin, largely rats, have limited the number of which the sex was determined. A description of the adult hybrids is deferred until after all the matings have been described.

Explanation of the Symbols used in Interpreting the Results.—It was pointed out by Spillman, following Bateson, that sex-linked inheritance in poultry could be accounted for on the assumption that the female is heterozygous for sex and the male homozygous, and that when in the female, the barred factor alone is present, it is repulsed by femaleness. We may give this interpretation a more concrete form, if we assume that the factor in question is not carried by the same chromosome that carries the factor for the female sex; *i. e.*, in the heterozygous female the chromosone that carries femaleness also lacks the factor for barring, and its mate that lacks the factor for femaleness carries the factor for barring. No interchange between the chromosomes (if two really exist) can take place, perhaps because they fail to pass through those stages in synezesis when such a process becomes possible.

If F = female, f its absence or male; B = barred, b its absence; N = black, then the formulas for the barred fowls will be:

Barred ♀	FNb	fNB
“ ♂	fNB	fNB

For the Langshan fowls, the formulas will be:

Black ♀	FNb	fNb
“ ♂	fNb	fNb

Whether the female-producing gamete of the Barred Rock really carries black or only the absence of barring will not affect the nominal results here recorded, but other experiments to be described by Goodale will show that “black” is probably present.

In order to see how these formulas apply to the crosses under consideration, let us take first the case of the cross between the Langshan hen and the Plymouth Rock cock (fig. 1). The formulæ are as follows:

	Langshan ♀	FNb	fNb
	Barred Rock ♂	fNB	fNB
F_1	Barred ♀	FNb	fNB
	“ ♂	fNb	fNB

F_2	Black ♀	FNb	fNb
	Barred ♀	FNb	fNB
	" ♂	fNB	fNB
	" ♂	fNB	fNb

Barring is dominant to self color, as is shown in the last case, where in the F_1 generation all the offspring are barred. In the second generation, there occur barred ♂ and both barred and black ♀. The grandmaternal color, black, appears in the grand-daughters and not in the grandsons.

Fig. 1.—*Cross of Plymouth Rock* ♂ *to Langshan* ♀

The reciprocal cross between the Barred Rock female and the Langshan male (fig. 2) may be represented as follows:

	Barred Rock ♀	FNb	fNB
	Langshan ♂	fNb	fNb
F_1	Black ♀	FNb	fNb
	Barred ♂	fNB	fNb
F_2	Barred ♀	FNb	fNB
	Black ♀	FNb	fNb
	Barred ♂	fNb	fNB
	Black ♂	fNb	fNb

Parental Matings.—(1) From the five Langshan hens by a Barred Rock male, there were 34 young, all barred: 12 were females and 8 were males (fig. 1):

FNb	fNb	Langshan	♀	
fNB	fNB	Barred Rock	♂	
FNb	fNB	Barred	♀	12
fNB	fNB	"	♂	8

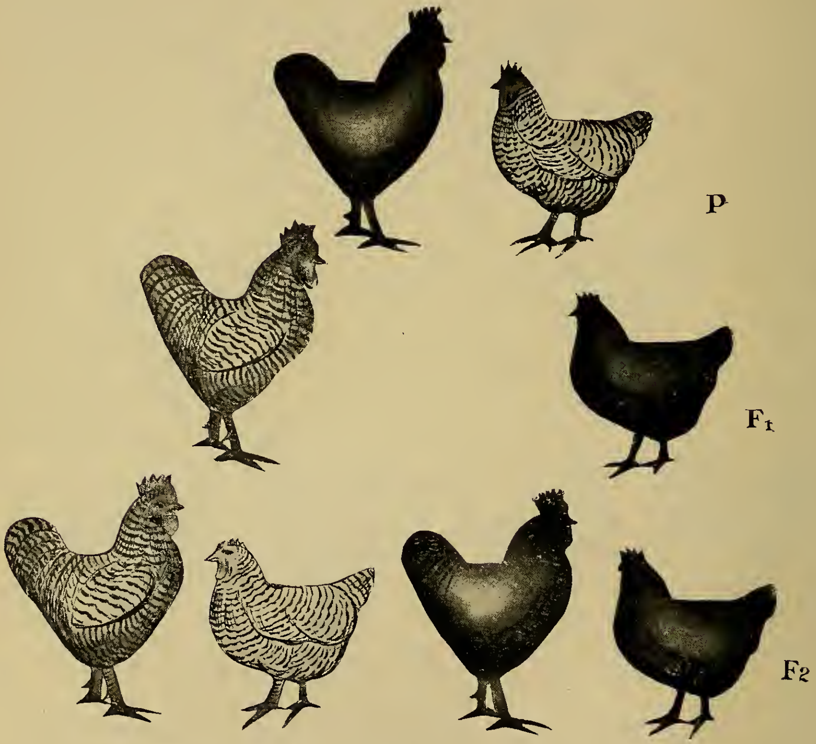

FIG. 2.—*Cross of Langshan ♂ to Plymouth Rock ♀*

(2) From the various barred females bred to a Langshan male, there were 20 barred (15 ♂) offspring and 25 black (16 ♀) (fig. 2):

FNb	fNB	Barred	♀	
fNb	fNb	Langshan	♂	
FNb	fNb	Black	♀	16
fNB	fNb	Barred	♂	15

F$_1$ Matings.—(3) Four barred F$_1$ females from (1) were bred to a barred male, No. 568, from (2). This was done because the only adult male, No. 784, from (1) did not mature until long after his sisters were laying, while a change of residence on the part of the writer prevented the accomplishment of the *inter se* mating. From the cross-mating, however, there were 25 barred (12 ♂ and 9 ♀) offspring and 13 black (8 ♀) (fig. 1). Expectation on the Spillman-Bateson hypothesis is 28½-9½. One individual, a male, with the gray spot reduced to a few plumules was excluded from the count as doubtful.

F_1	FNb	fNB	Barred	♀	
	fNB	fNb	"	♂	
F_2	FNb	fNB	Barred	♀	9
	FNb	fNb	Black	♀	8
	fNB	fNB	Barred	♂	12
	fNB	fNb	"	♂	

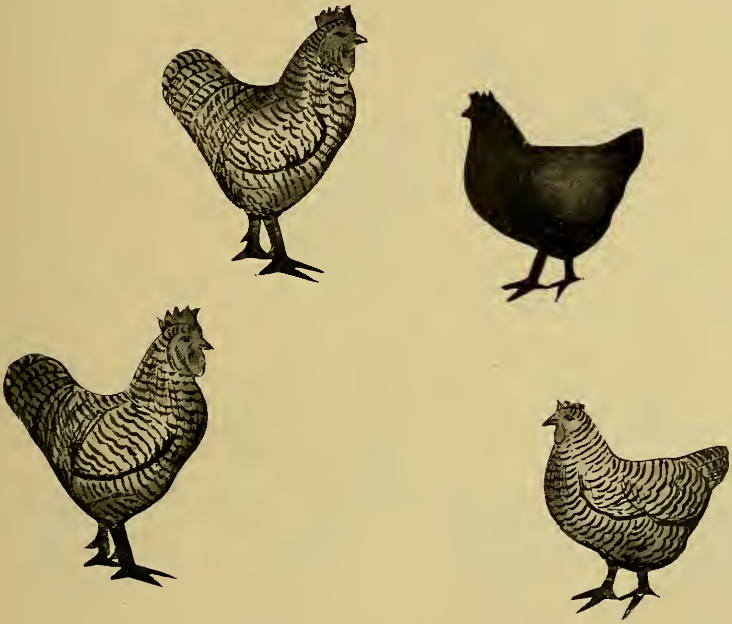

Fig. 3.—*Cross of barred ♂ to F_1 black ♀*

(4*a*) The 6 black females from (2) were mated to a litter barred brother, No. 569, giving 41 young; 16 of which were black (8 ♂, 6 ♀) and 25 barred (6 ♂, 10 ♀). (4*b*) Later, they were bred to No. 784, giving 22 young; 7 were black (0 ♂, 1 ♀) and 15 barred (5 ♂, 1 ♀). The combined results of these matings were 63 young, of which 23 were black (8 ♂, 7 ♀) and 40 barred (11 ♂, 11 ♀) (fig. 2). The departure from the expected ratio of 31½ is considerable.

F_1	FNb fNb	Black ♀	
	fNB fNb	Barred ♂	
F_2	FNb fNB	Barred ♀	10 + 1
	FNb fNb	Black ♀	6 + 1
	fNb fNB	Barred ♂	6 + 5
	fNb fNb	Black ♂	8 + 6

Back Matings.—(5) The 6 black F_1 females used in (3) and (4) were bred to a pure Barred Rock male and gave 9 barred young, fulfilling expectation (fig. 3).

FNb fNb	Black ♀
fNB fNB	Barred ♂
FNb fNB	Barred ♀
fNb fNB	" ♂

Fig. 4.—*Cross of Langshan ♂ to F_1 barred ♀*

(6) The 4 barred F_1 females used in (3) were bred to a pure Langshan male. Of the 30 offspring, 14 were barred (1 ♂, 1 ♀) and 16 black (0 ♂, 3 ♀). This corresponds closely to the expected equality in ratio (fig. 4), except for the possible barred female. The determination of sex in this case was made on rather poorly preserved material.

FNb	fNB	Barred ♀	
fNb	fNb	Black ♂	

FNb	fNb	Black ♀	
fNB	fNb	Barred ♂	

(7) Several of the parental barred females were mated with No. 568, barred F_1 ♂, giving 8 barred (3 ♀, 1 ♂) and 3 black (1 ♀).

FNb	fNB	Barred ♀	
fNB	fNb	" ♂	

FNb	fNB	Barred ♀	3
FNb	fNb	Black ♀	1
fNB	fNB	Barred ♂	1
fNB	fNb	" ♂	

(8) Four of the parental Langshan females mated to No. 569, barred F_1 male, gave 17 barred (6 ♀, 2 ♂) and 13 black (4 ♂; no record for ♀).

FNb	fNb	Black ♀	
fNB	fNb	Barred ♂	

FNb	fNB	Barred ♀	6
FNb	fNb	Black ♀	?
fNb	fNB	Barred ♂	2
fNb	fNb	Black ♂	4

(9) Two of the barred F_1 females used in (3) were bred to a Rock male, not, however, of the Latham strain. There were only 5 chicks, all barred.

FNb	fNB	Barred ♀	
fNB	fNB	" ♂	

FNb	fNB	Barred ♀	
fNB	fNB	" ♂	

Summary.—Expectation in all these matings has been closely fulfilled (with the exception of No. 4 and perhaps No. 6), on the assumption that the barred female is heterozygous for both barring and sex, both femaleness and barring being dominants and that the two factors do not occur in the same gamete.

Description of F_1 Adult Plumage.—The males (Plate XVII, figs. 5 and 7) resemble one another closely and together with the barred F_1 females are very suggestive of the Coucou de Malines, a Belgian breed. The barring of the individual feathers of the males (Plate XVIII, figs. 10, 13) is less sharp and regular than that of the parental Rocks (Plate XVIII, fig. 8), while the dark bars tend to run together, particularly in wings and tail, and at the same time, the light bars become more or less smoky. The primaries, indeed, can be called barred only by courtesy, for the light bars are only represented by white splashes along the shaft (Plate XVIII, fig. 14). This region, however, is one in which the fanciers have found great difficulty in producing even and regular barring.

One barred male is particularly interesting in that a few feathers show distinctly the Jungle coloration (Plate XVIII, fig. 12) which probably exists as a cryptomere in the Langshans.

All the males have numerous feathers wholly or partly black (Plate XIX, figs. *p-u*) and this is true also for the barred females. The last, except for the black feathers, are well barred (Plate XVII, fig. 6) and can scarcely be distinguished from the parental stock. Even the individual feathers, except the remiges and retrices in which the bars run together, conform closely to the pattern shown by many thoroughbred Barred Rocks.

The color of the F_1 black females (Plate XVII, fig. 8) is indistinguishable from the parental Langshans.

Comparatively few members of the F_2 generation reached maturity. The only points of particular interest are the appearance of very light as well as dark males, of both black and barred males having a few feathers showing the Jungle fowl coloration and of dark-colored females with the barring somewhat blurred.

The non-appearance of game (Jungle) colored birds in F_2 is due presumably to the fact that black is duplex in both Rocks and Langshans, and thus the Jungle fowl color is concealed. There are, however, indications that black may sometimes exist in a simplex condition among Rocks; so that, if suitable matings were made, the Jungle fowl color might appear. Unless the occasional feather showing Jungle fowl color is due to a simplex condition of black, its appearance may mean that hybridization in some way has upset the usual complete dominance of duplex black over the Jungle fowl coloration.[3]

As already stated, Pearl and Surface have published their results in crossing Plymouth Rocks and Cornish Indian Game. Our results entirely accord with theirs, as far as inheritance of barring is involved. They classify their birds as barred and non-barred, ignoring intentionally the differences among the non-barred birds. Our results are simpler, in so far as all our non-barred birds are black, but the principle involved is the same in both cases. Pearl and Surface have also made all possible back crosses between the parents and the F_1 generation. Our results are in entire harmony with theirs, but they have the advantage of a larger number of offspring in their matings.

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[3] Davenport, 1909, p. 72.

Shank Color.—The color of the shanks of all chicks hatched was recorded, but the color often changes as the birds become older, so these records prove to be of small value. The change in shank color is particularly characteristic for the class called yellowish or flesh-colored black. This class may give rise to all three of the adult shank colors recognized, black, gray and yellow. Black-shanked chicks seem always to develop into black-shanked adults, and while yellow-shanked chicks probably do not produce black-shanked adults, they may give rise to either yellow or gray-shanked adults.

The infantile shanks among the F_2 not only show the expected classes, but these classes pass by imperceptible grades into one another. Frequently, one part of the shank, particularly the toes, differs from the remainder; while, in many cases, the distribution of color forms a mottled pattern. The distribution of color upon the toes is likewise extremely variable and often asymmetrical. In almost every case, however, some part of the toes is flesh or yellow. This variation is due, presumably, to some extension or restriction factor. Similar variation in the distribution of color in F_1 was also recorded.

The shank color of the F_1 adults falls into two classes, black and gray. The term gray is used rather loosely to cover a particular though somewhat variable coloration of the shanks. At a distance, the shanks do indeed appear gray just as a Barred Rock appears gray, and just as the "gray" of the Rocks resolves into a pattern on closer inspection, so the gray of the shanks is not a single or uniform color. For convenience of description, we may say that the ground color is steel gray, variously mottled with patches of darker gray or of black. Parts of the shank often have a bluish cast. The posterior side and particularly the bottoms of the feet are somewhat flesh colored. Mottling does not as a rule occur on the bottom of the feet, so that though the term gray is applied to them in a later paragraph, it is to be understood that they do not have the same appearance on the shanks proper but rather are a grayish flesh, self color. The three classes of black, gray and yellow do not grade into each other.

The six F_1 black females had black shanks. The three males and the four barred females had gray shanks. Apparently, we have here a case of sex-linked inheritance. This, however, may not be the case but may be due rather to the black spreading over onto the shanks just as it often spreads over onto the comb. In the barred birds, we may suppose that the barring factor operates to prevent the spreading of black over the shanks, just as it also produces the characteristic barring of the feathers of the boot. Thus, the colors hypostatic to black are revealed. However this may be, in F_2 the black birds again have black shanks, but the bottoms of their feet, which are usually incompletely covered by black, are either gray or yellow. The allelomorphs involved, then, are gray versus yellow (or $Gray_2$, $Yellow_2$, X, No $gray_2$, $Yellow_2$), the latter being recessive to the former. Moreover, among the barred birds, only gray or yellow shanks appear, or in other words, gray-shanked birds always have gray soles, yellow shanked birds yellow soles, but black-shanked birds may have either gray or yellow soles.

Since, then, the black-shanked condition is due to an extension of the general black color of the body, we need consider further only the relation of gray to yellow, the determinations being made, of course, only on the bottoms of the feet and when the birds were several months old. In F_1, there were only gray or pinkish gray feet, and, therefore, there is no evidence that gray is sex-linked. Moreover, since no other color than yellow appeared in F_2, yellow is probably common to both Langshan and Rocks, so that absence of gray in this case means yellow. In F_2, not all the adults were available for study, as the importance of foot color was not realized until after many of the birds had been disposed of, but in 17 cases, 13 were gray and 4 yellow. The back mating of F_1 gray male to P_1 gray (Langshan) female gave 6 gray. The back mating of P_1 yellow (Rock) male to F_1 gray (black plumage) female gave 6 gray to 2 yellow. These results indicate, then, that gray and yellow feet (or shanks, leaving out of consideration the supermelanic coat) behave in simple Mendelian fashion.

We have suggested that black individuals have black shanks, because a restriction factor is absent from these birds, so that the body color spreads out as a self color over the shanks. Such a "restriction" factor would be sex-linked. Is it, then, the same as the barring factor? If it were a separate factor, we should expect that, in F_2, a certain amount of segregation would take place. This has not been observed, so that it seems probable that the black shanks of the black birds are due to the absence of the barring factor and the mottled shanks to its presence, unless some "association" exists. Thus, the presence of the barring factor results in two (perhaps three) distinct somatic conditions, viz.: barred feathers and mottled shanks, and, as a possible third, the gray occipital spot of young chicks. In other words, we have two or more unit characters resulting from the operation of a single factor.

There are some considerations of a practical nature resulting from the relations between shank color and sole color which should be mentioned. If the black color covered the entire foot, we should be unable to determine what color underlay the black, except perhaps by long-continued breeding tests. Gray would, therefore, appear to be a sex-linked character. In F_2, however, the results would appear peculiar, for while we should have the three classes of black, gray and yellow shanks, the black shanks would always appear associated with black birds, while gray and yellow shanks would go with barred birds. This conclusion does not agree with the results expected when two independent sex-linked characters are involved. In F_3, the observed results would be very complicated. A discussion of the various possible explanations which might be devised to meet the situation would hardly be profitable here, but a comparison of the results expected when the color of the soles of the feet is taken into account with those when they are omitted may furnish the key to similar cases.

Booting.—The Barred Rocks are typically clean shanked, but occasionally a bird is found with a few "stubs." The boot of the Langshan corresponds approximately to that shown in many of the older pictures of Cochins and Brahmas and may perhaps be regarded as the primitive type from which the modern highly developed boot of Cochins has been developed.

For the F_1 generation, booting was recorded on the chicks as "present" in all cases but two. These two occur among the first four recorded, so that it is possible that, if only a few stubs were present, they may have been regarded as slightly atypical clean shanks. In one other case, booting was nearly absent. Of the 13 adults, the three males and four barred females were alike in that the amount of booting was decidedly scanty, being reduced to about two or three imperfect rows of rather short feathers. The six black females were more variable, due apparently to greater variation in length of feather rather than to variation in the number of rows, the result being a greater variation in amount of boot.

A much larger range in the amount of booting appeared in the next generation. The following relative grades of boot in the chicks were recognized: A, B, C, D, E and absent. No emphasis is to be laid on these degrees, except in so far as they show the general distribution of boot. A and B correspond approximately to that of the parental Langshan, and C and D to that of the F_1 hybrids. Among the adults, not only were there some birds heavily booted like the Langshans, some like the hybrid and others clean-shanked like the Rocks, but one bird had two rows of rather long feathers and one bird four rows of short feathers, indicating that there is more than one component to boot.

Table I

Distribution of Booting in F_2 and $F_{1\cdot 5}$

Mating No.	A	B	C	D	E	Absent	Total	Remarks
3	1	7	1	14	0	6	29	F_1 females from 1 × F_1 male from 2.
4*a*	0	10	2	8	3	4	27	F_1 females from 2 × litter brother.
4*b*	0	6	3	4	5	3	21	F_1 females from 2 × reciprocal litter brother.
5	0	0	0	0	2	6	8	F_1 females from 2 × Rock male.
6	0	7	10	11	2	0	30	F_1 females from 1 × Langshan male.
7	0	0	0	3	4	3	10	Female Rocks × male from 1.
8	3	13	4	10	0	0	30	Female Langshans × male from 1.

Table II

Mating No.	Generation	Expectation			Observed		Total	Remarks
		Per cent clean	Based on total recorded					
			Clean	Booted	Clean	Booted		
1	F_1	0	0	all	2[4]	24	26	Langshan females × Rock male.
2	F_1	0	0	all	0	32	32	Rock females × Langshan male.
3	F_2	18.75	5.4	23.6	6	23	29	Females from 1 × male from 2.
4*a* & *b*	F_2	12.5	6.	42.	7	41	48	Females from 2 × males from both 1 and 2.
5	$F_{1\cdot 5}$	50	4.	4.	6	2	8	Females from 2 × Rock male.
6	$F_{1\cdot 5}$	0	0	all	0	30	30	Females from 1 × Langshan male.
7	$F_{1\cdot 5}$	37.5	3.75	6.25	3	7	10	Female Rocks, male from 1.
8	$F_{1\cdot 5}$	0	0	all	0	30	30	Female Langshans, male from 1.

The results are in entire agreement with Davenport's and confirm his theory of an inhibitor. The back matings suggest that the amount of boot varies with the increase or decrease in the amount of booted "blood". There are, however, one or two other theoretical ways of accounting for the observed facts. If we assume that booting is common to both Langshans and Rocks and is recessive to a pair of complementary factors, both

---

[4] See above in text.

of which must be present and one of which must be duplex in order to bring about a complete suppression of the booting, the outcome approximates the observed ratios of booted to non-booted.

By assuming that the factor which exerts its effect in either the duplex or simplex condition is sex-linked, the results shown in Table II are obtained. The distribution of the sexes is not given, because the numbers available are inadequate for the solution of a problem as complex as the present one. While the correspondence between theory and observation in this case is close, an attempt to apply it to Davenport's data resulted in only partial success. This may mean only that more or different factors are involved in the production of boot in Brahmas, Cochins and Silkies than in Langshans, or that the factors causing the inhibition of boot development in Plymouth Rocks are different from those of Tosa, Minorca and other smooth-shanked birds used by Davenport. Among possible factors concerned in boot production should be included those general factors which affect feather growth, in the same way as barring or other color factors control the color of the feathers of the boot as well as those of the body.

Down Colors.—The Langshan chick is black dorsally but yellowish white beneath and has white wing tips. The white ventral area often extends upwards, particularly on the head, so that in some cases in this region only the crown and nape remain black. The white area of the wing tips at the same time increases in size, so that the black dorsal surface becomes reduced in amount.

The Rock chick, however, though black dorsally except for the gray occipital spot, is usually dark gray beneath, but very often there are several light gray or white areas, which occasionally become more or less confluent, and in extreme cases most of the ventral surface is white and to a limited degree overlaps the Langshan type.

In classifying the chicks, all were called "black," *i. e.,* of Langshan type, in which at most the breast region was partly pigmented. This region in the Barred Rock chick is the last to lose pigment. All others were classified as "barred". While this mode of treatment proved to be inadequate for the entire solution of the inter-relations of these characters, it was found, first, that both types appear in F_1, but that the "blacks" are far more numerous than the "barreds"; second, that "blacks" F_1 interbred or backmated throw some "barreds", but not in simple Mendelian proportions.

CROSSES BETWEEN AMERICAN DOMINIQUE FEMALES AND LANGSHAN MALES

Parent Generation.—Both the hens and the cock were purchased from breeders of these strains.[5] The one peculiarity calling for notice is the occasional occurrence in the Dominique hens of black or partly black feathers (Plate XIX, figs. *b, d, e*). One of the four hens used had several such feathers. The other hens were free from them. The American Dominiques have barred feathers (Plate XIX, figs. *a, c*), essentially like those of Plymouth Rocks.

F_1 Generation from Langshan ♂ by Dominique ♀.—About 15 offspring were reared; the hens were black and the cockerels barred. Of these, five hens and two cocks were bred from. The black hens were like the father as to color; the males were barred like the mother, except that a large number of black feathers were present—some feathers entirely black (Plate XIX, figs. *r* and *t*) and others barred and black (Plate XIX, figs. *p, q, s, u*).

F_2 Generation.—In the second generation, there were recorded 15 blacks and 14 barred birds. Three of the latter died or were killed by animals. Of the remaining, there were 11 male and 15 females tabulated as to color as follows:

	♀	♂
Barred	8	4
Black	7	7

The barred birds were fairly uniform. They were kept for about two months, when their feathers were well developed. A few birds were distinctly darker than the rest, and one bird was much lighter. Certain details regarding white feathers in the wings will be spoken of later.

Back Cross of F_1 ♂ (Barred) to Dominique ♀.—One of the sons was crossed to the four hens that had produced his generation. A first census of the offspring, when the birds were small, gave 19 barred and 4 black birds. A later count when the birds were older gave 14 barred and 4 black. Five barred birds had disappeared. The distribution of color and sex of 16 of these birds was as follows:

	♀	♂
Barred	7	5
Black	4	0

---

[5] The Dominiques came from W. H. Davenport, Colrain, Mass. The source of the Langshans is given on page 115.

There were also two barred birds whose sex was omitted by mistake in the records. The expectation is three barred to one black, which is closely realized.

Back Cross of F_1 Black ♀ to Langshan ♂.—Five black hens were bred to a Langshan cock of the same strain but not the actual father of these hens. Another black hen that came from a similar cross with a Plymouth Rock was also present in the same pen, so that some of the offspring may have come from this hen also. There were 18 black young, of which 11 were males and 7 females. In addition, however, there was one barred chick. Now, the black hens had been with a barred cock to give the F_2 generation. They had been for three weeks with the Langshan male before the eggs fertilized by the black cock were kept for incubation. There can be little doubt that one of the spermatozoa of the original male had carried over and produced this bird. If this case is thrown out, the results are consistent.

Other Features of the Crosses.—The Langshans have feathered tarsus (booted); the Dominiques have clean shanks. All of the F_1s recorded were booted, though not strongly. In the F_2 generation, there were 14 booted and 11 clean shank, distributed as follows:

	Booted		Clean	
	♀	♂	♀	♂
Barred	7	2	1	2
Black	1	4	5	3

It is clear that booted shanks dominate[6] but imperfectly in this cross, as in other crosses of poultry. Some of the F_2 offspring had heavily booted legs; others were like the F_1 generation. No sharp line between the classes in the F_2 generation could be drawn.

There is no evidence of any association here between black and booted (the paternal combination) and barred and clean-shanked (the maternal combination).

When the barred and booted F_1 male was bred to four Dominique hens, the results are shown in the next table:

	Booted		Clean	
	♀	♂	♀	♂
Barred	6	1	1	4
Black	1	0	3	0

---

[6] In the sense that an inhibitor is present in clean shanks.

In this case, the male was heterozygous for condition of tarsus; the hens pure and recessive. The result calls for equal distribution of booted and clean shanks unless "association" occurs. The numbers are too small to have any significance. Even as they stand, however, they have no meaning, if coupling be made responsible for the distribution of the characters.

When the Langshan male was crossed to the black hens (both sexes booted, but the hens heterozygous) all of the offspring were booted, which is in accordance with dominance of booted shanks.

White Feathers in Wings.—In the F_2 young birds, the presence of white and partly white feathers in the wings was noticed (Plate XIX, figs. *f-n*, *o*, *v* and *w*). They were most obvious in the black birds, perhaps because of the sharper contrast. These feathers are some of the primaries and a few of the coverts at the base of the primaries. As shown in Plate XIX, figs. *f* to *k*, they are rarely pure white, but often mottled or splotched. They were not recorded in the F_1 birds, and if present they were overlooked. The records of birds without and with these white feathers were as follows:

	♀	♂
Barred, no white	6	4
" with "	2	0
Black, no white	6	4
" with "	1	3

In all, there were 20 chicks without and 6 with white feathers. This looks like a case of Mendelian inheritance, but it may be purely a coincidence. We do not know how often such feathers occur in chicks of the original breeds, or whether they are only juvenile, or physiological effects of the condition of the bird. Probably they would have disappeared in later molts, had the chicks been kept longer.

When the Langshan cock was bred to the black F_1 hens, 4 of the chicks had no white and 14 had white in the wings. If the black male is heterozygous for this condition, the result is not in accordance with the assumption that this is a Mendelian recessive character.

When the Dominique hens were bred to the F_1 barred males, there was no white in the 15 recorded offspring. This result is not in harmony with the same supposition, but the black male used in the last experiment was not the same father as for the barred males of the first cross. The father of the barred male in the first case was a brother of this one. It is still possible, therefore, that one male was homozygous and the other heterozygous for the white-feathered condition. Without, however, fuller information, not much weight can be given to these results.

Color of Legs.—It has been stated by Bateson and by Pearl that yellow and black shanks in certain breeds of poultry show "sex-linked" inheritance. This is not apparent in the Langshan-Dominique crosses, except in so far as black shanks accompany black color of feathers. For example, in the F_2 generation, there are recorded 13 black birds with black legs. Of these, 5 were deep yellow on the under side of the feet. In addition, there was one male that had yellow shanks and yellow under the feet. There were recorded 12 barred F_2 chicks with yellow shanks. Of these 12 birds, 4 are recorded as having very pale yellow or whitish legs. It would appear from this case that black and yellow shanks accompany black and barred plumage, at least as a rule.

In the back cross of the F_1 barred male to the parent Dominique hens, in which there were barred males and females and only black females, all 4 of the black birds had black legs, while all 12 barred birds had yellow or pale legs. Among these 12 barred birds, there were 5 with pale legs; in 2 of these and in one yellow, there were spots of black or dark color, at least on the tarsus.

These rather meager figures, as far as they go, show that shank character and color of plumage go together, and that black shanks and yellow shanks are only an accompaniment to sex-linked inheritance of plumage. The data are manifestly few, however, and it may well happen that the two characters may appear disassociated.

Color of Bill.—The color of the bill seems to run a parallel course. Full records for the back cross given above were kept. Here, 13 barred birds had yellow bills and 5 black hens had black bills, but one of the latter had much yellow on it, and two of the former had black: one was black with yellow tip and the other was yellow and black. There is much variability in the color of the bill, and the above statements are insufficient to warrant any generalizations.

THEORETICAL CONSIDERATIONS

The current formula for sex inheritance in fowls represents the female as heterozygous for sex, F-O, and the male homozygous, O-O. If F is identified with a special chromosome connected with sex determination, the formula calls for one more chromosome in the female than in the male. At present, evidence on this point is conflicting and insufficient. It is true that Guyer has described two kinds of spermatozoa in the male, one with an X and one without. If this X is the same as in other animals, then the spermatozoa containing it must be female producing, and the female should contain one more chromosome than the male. This means that the male and not the female is heterozygous for sex. The experimental evidence is flatly opposed to this latter interpretation, and, therefore, until Guyer's evidence is confirmed or refuted, the case must be left open.

On the other hand, if, as the experimental evidence shows, barring is "repulsed" by femaleness and if both of these factors are carried by chromosomes, the formulas are deficient in having no chromosome to carry barring,—a contradiction of terms. It may be, however, that the X-chromosome in fowls has a mate which we may call Y which would carry barring but not femaleness. The formulæ would then be:

Female.............................. X — Y
Male................................ Y — Y

XY Female
YY Male.

On this interpretation, the factor for femaleness would be contained in X but absent from Y, while barring is contained in Y. This scheme is compatible with the experimental evidence and gives consistent results for all combinations.

The irregularities that have been observed in the "reduction division" both in birds and in man suggest the possibility that the sex chromosomes are united to other chromosomes as in some other animals. If the union is variable, as in the nematodes, it may be that the X and the Y (if Y exists) may sometimes pass to the poles of the spindle during reduction in conjunction with other chromosomes and sometimes be free to pass to the poles independently. If further study should establish this view, it will have a very direct bearing on the relations discussed above. If the factor F for femaleness is carried by chromosomes attached to one member of another pair, the mate of this member may be the chromosome that carries the factor for barring. If this were the case, however, interchange between these two members would lead to the barring factor being transferred to the chromosome attached to the sex chromosome. This is in contradiction to the experimental evidence which would lead rather to the conclusion that a Y element lacking the factor for barring is present. The Y may be attached to the mate of the chromosome carrying the sex factor.

At present, only a few cases have been discovered in which a sex-linked character is dominant, viz.: in fowls and in one character in *Drosophila*. The only other cases, besides the one in poultry in which sex-linked inheritance occurs and sex is heterozygous in the females, is that of *Abraxas* and that of canaries. In both of the latter, the sex-linked factor is recessive. There are no *a priori* grounds why a character of this sort may not be dominant, if some other Mendelian characters may also be dominant.

The factor for black, N, is treated in our formulæ as present in all of the gametes both of the female and of the male. It is not allelomorphic to barring, B, although its presence in the female-producing egg when barring is present in the correlated male-producing egg may appear to bear this interpretation. From the chromosome point of view black may be, so far as we know, in other chromosomes than those carrying barring; hence its more general distribution.

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PLATE XVII

BARRED PLYMOUTH ROCKS, LANGSHANS AND THEIR CROSS-BRED OFFSPRING

Fig. 1. Barred Plymouth Rock cock.
Fig. 2. One of the parental Langshan hens.
Fig. 3. Langshan cock. Stock of Mr. Ives.
Fig. 4. One of the parental barred hens. This particular hen is an F_1 from White Rock male X Barred Rock female.
Figs. 5 and 6. The F_1 from Barred Rock cock by Langshan hen.
Figs. 7 and 8. The F_1 from Langshan cock by Barred Rock hen.

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2

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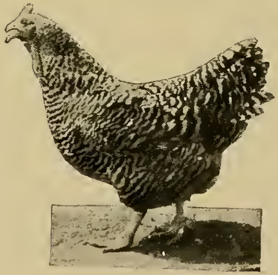

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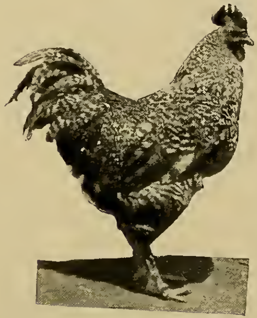

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PLATE XVIII

FEATHERS OF LANGSHANS, BARRED PLYMOUTH ROCKS AND THEIR OFFSPRING

Hackle feathers (except 11 and 14) from the various types of birds used in the experiments.

FIG. 1. From Langshan female.
FIG. 2. From F_1 black females.
FIGS. 3 and 4. From a pure bred Barred Rock female.
FIG. 5. From a second Barred Rock female. Note the differences in the evenness of the barring.
FIG. 6. From the hen shown in Plate XVII, Fig. 4.
FIG. 7. From F_1 barred female.
FIG. 8. From a pure bred Barred Rock cock.
FIG. 9. From same bird, illustrating a partially black feather occurring in pure bred stock.
FIGS. 10, 11, 12, 14. From F_1 bird shown in Plate XVII, Fig. 5.
FIG. 10. Hackle feather.
FIG. 11. Breast feather.
FIG. 12. Shows the Jungle fowl coloration.
FIG. 13. From bird shown in Plate XVII, Fig. 7.
FIG. 14. Primary, to show reduction in barring.


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PLATE XIX

FEATHERS OF AMERICAN DOMINIQUE FOWL

FIG. *a*. Dominique hen. Barred feather.
FIG. *b*. Dominique hen. Black feather.
FIG. *c*. Dominique hen. Barred feather.
FIG. *d*. Dominique hen. Black feather.
FIG. *e*. Dominique hen. Black feather.
FIGS. *f-k*. Consecutive primaries of barred F_2, showing four nearly white feathers.
FIGS. *l-n*. Three white covert feathers from wing.
FIG. *o*. Consecutive primaries of black F_2, showing some white at tip.
FIGS. *p-u*. Tail coverts of F_1 barred male, showing uniform black regions and barring in same feather.
FIG. *v*. Wing of black F_2, showing white tips to primaries and two white covert feathers at their base.
FIG. *w*. Wing of barred F_2, showing a nearly white primary and irregular barring on some other feathers.


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ON THE DICTYONEMA-FAUNA OF NAVY ISLAND, NEW BRUNSWICK

BY

F. F. Hahn

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ON THE DICTYONEMA-FAUNA OF NAVY ISLAND, NEW BRUNSWICK

BY F. F. HAHN

(*Presented by title before the Academy, 13 May, 1912*)

CONTENTS

INTRODUCTION

One of the older modes of paleontological investigation, the study of the range and significance of variability, seems now to be somewhat overtaken by and neglected on account of the excellent results obtained in the study of the stages of earliest youth, growth and senescence. My own studies on Jurassic invertebrates, which made me familiar with a vast number of individuals of many species, brought me to the conviction that a combination of these two modes of treatment would, in every case where the given material is sufficient, lead to an advance greater than would be possible by either method alone. Thus, when I worked over in the Museum of Columbia University the wonderful collections from the Dictyonema-shales made by G. van Ingen and W. D. Matthew at Navy Island, N. B., from Division III, b, c, commonly regarded as Upper Cambrian,[1] of course my first thought was to see whether I could find any relationship between the range of variability and the history of the races among the Dictyonemas. And this animal association seemed well adapted to this kind of study, for though the Dictyonema-shales contain a vast number of individuals, there are only four species common, two of which are graptolites.

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[1] According to the trilobites found in Sweden and England, it must apparently be placed at the base of Ordovician.

Description: Generally infundibuliform, branches more or less parallel, frequently dividing, width of tissue 9-10 mm., cross-threads somewhat irregular, of medium number; open rectangular meshes; thecæ 15 to 17, projecting, of medium size.

Notes: Slight changes of the characters are fully shown on the diagram, Plate XX. Greatest length observed about 200 mm., width 190 mm.; approximately 2 x 150 branches.

The variation of the number of thecæ is marked, 16 being present on the American examples, but only 10-15 in 10 mm. on the European examples. This fails to be of general value, as G. F. Matthew has pointed out, since the figures of Brögger (5) and Tullberg (8) also exhibited 16 thecæ and Westergård states recently a usual number of 15-16 thecæ on the Swedish examples ((4), p. 58). When comparing the form, collected by Prof. A. W. Grabau from Skåne (region of Fogelsång), with the American specimens, a more delicate character of the whole tissue of the European type is apparently the one observable difference on which a separation of var. *acadica* Matth. and "forma *typica*" of the Swedish authors can be based.

Var. **conferta** Linrs (ms.)[11]

Apotypes:

(6) 1860. GÖPPERT, pl. 36, fig. 11, 4.
(9) 1861. SALTER, Geol. Survey Gr. Brit., Mem. 3, pl. 4, fig. 1.
1881. SALTER, Geol. Survey Gr. Brit., sec. ed., p. 535, pl. 41, figs. 1, *1a*, *1b*.
(8) 1882. TULLBERG, p. 20, pl. 3, fig. 3 (1, 2?).
(4) 1909. WESTERGÅRD, pl. 3, fig. 7.

Description: Characterized by Brögger ((5), p. 36) as having very fine and close network and cross-threads of the same kind.

Matthew[12] added "commonly vasiform, cross-threads more frequent than in *acadica* (5-7). 15-17 thecæ are usually met with in 10 mm."

I have observed even 18 on a typical specimen; young specimens often show only 14-15 thecæ. The rigid aspect of the branches and their regular branching, which commonly takes place in the same level, seem rather important additional features. Here, too, a little more delicate structure of the whole tissue distinguishes the Swedish specimens, so that Westergård found 13 branches in 10 mm. of width, while 8-10 branches may be usually numbered on the American variety. The largest observed colony measures 22 mm. in width, occupied by 19 branches, and 82 mm. in length.

---

[11] Brögger (5) furnished as long ago as 1882 an undoubted description of this form, while Pocta created his species "*conferta*" not earlier than 1894 (Système silurien, Bryozoaires, etc., Vol. VIII, t. 1er, p. 194). The last ought to be renamed, if this is necessary at all.

[12] *Loc. cit.*

Var. **norwegica** Kjerulf.

Apotypes:

(7) 1865. Kjerulf, p. 2, fig. 4 (1-3).
(2) 1906. Moberg, pl. 1, fig. 7.
(4) 1909. Westergård, pl. 30, figs. 8, 9.

Description: After Brögger ((5), p. 36), thick cross-threads, close network; small, short, rounded meshes.

I observed only 15 thecæ. Young stages like var. *acadica*. Crossings of all kinds into true *acadica* occur. A slight distinction between my specimens and the Swedish ones is in so far recognizable as the first are furnished with a little more elongated meshes, but they can be precisely compared with Westergård's figures. My largest colony is 40 by 40 mm., while Westergård cited a specimen 115 by 30 mm. in size.

Var. **ruedemanni** nom. nov.

Typical figures:

(1) 1904. R. Ruedemann, pl. 1, figs. 16-20, 22 (12-15, non fig. 21).

Apotypes:

(10) 1895. G. F. Matthew, Trans. N. Y. Acad. Sci., Vol. 14, pl. 49, figs. 1, 2. (The figures are not quite correct, showing a too open tissue.)

Compare

(5) 1882. Brögger, pl. 12, fig. 19.

Description: In nepiastic stage strongly branching at an almost acute angle. Full-grown specimens with crowded, more or less parallel branches up to 14 in 10 mm. width. Dissepiments appearing early, but afterwards irregularly scattered. Thecæ small, not much projecting. Adhesion organs relatively common.

Notes: Generally funnelform, sometimes of intermediate shape (pyriform) towards the vasiform variety "*conferta*." Measurement of a typical pyriform specimen:

Length	Width in mm.
10	10
20	25
25	35
48	65

The specimens obtained from Navy Island (N. B.) fully agree with Ruedemann's figures, but several specimens considerably surpass the given characters in the same direction. In Europe it is rare, but abundant in America, at Navy Island as well as at Schaghticoke. Largest measured colony 165 mm. in length and 140 mm. in width.

Var. **desmograptoidea** var. nov.

Description: Infundibuliform. Open meshwork of irregular, mostly suboval fenestrules. Branches undulating and sometimes coalescent. Dissepiments quite irregular, partly thickened. Thecæ 15 in 10 mm., not much projecting, rarely visible.

Note: Sometimes an old stage of var. *acadica* has these characters.

J. Hall's[13] *Dictyonema irregularis* resembles most this variety, but has a closer arrangement of the branches (25-28 in 1 inch) and occurs in higher Ordovician of Canada and Great Britain. *Dictyonema homfrayi,* described by T. Hopkinson and Ch. Lapworth,[14] seems to be a closely related species. *Desmograptus intricatus,* as shown in fig. 30, p. 609, by Ruedemann (1), exhibits exactly the same type in early stages, though belonging to the Chazy and having appressed thecæ. No well-preserved, large specimens are known, but several pieces are found indicating a width of the colony of more than 60 mm.

Staurograptus dichotomus Emmons var. **apertus** Rued.

(1) 1904. R. RUEDEMANN, pp. 612-614, pl. 2.

(11) 1891. G. F. MATTHEW, "*Bryograptus kjerulfi,*" Trans. Roy. Soc. Canada, Sect. IV, No. VI, p. 35.

1892. G. F. MATTHEW, "*Bryograptus patens* Matth.," No. VII, p. 95, figs. 1*a*, 1*d* (excl. lower figure of 16).

(10) 1895. G. F. MATTHEW, *id.*, p. 268, pl. 48, fig. 4 (?).

1895. G. F. MATTHEW, "*Bryograptus lentus* Matth.," *id.*, p. 270, pl. 48, fig. 2.

1895. G. F. MATTHEW, "*Clonograptus proximatus* Matth.," *id.*, p. 265, pl. 48, fig. 1.

In 1895, G. F. Matthew tried to keep separate five species of *Clonograptus* and *Bryograptus,* occurring in Division 3, band c on Navy Island, N. B. In 1903, Ruedemann[15] followed him, believing that four of Matthew's species were again recognizable, but a year later, in his Monograph on the Graptolites, he came to the conclusion that practically all these species and even genera present only definite stages of growth and preservation of *Staurograptus dichotomus,* a species established by Emmons in 1855, but rather dubious up to 1904. Ruedemann, indeed, furnished such a description and figures of this species, especially of the variety *"aperta,"* that complete identity with the species of Matthew enumerated above becomes apparent, if we look over the types of Matthew, which fortunately were in part accessible to me.

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[13] Canadian Organic Remains. Geol. Surv. Can., Dec. 2, p. 136, pl. 20, figs. 1, 2. 1868.

[14] Graptolites of the Arenig and Llandeilo rocks of St. David's. Quart. Journ. Geol. Soc. London, Vol. 31, p. 668, pl. 36, fig. 13. 1875.

[15] "The Cambric *Dictyonema* fauna in the Slate Belt of Eastern New York." N. Y. St. Pal. Ann. Rep., Bull. 69, p. 938.

The type specimen of *Clonograptus proximatus* (1895, pl. 48, Figs. 1*a*, 1*d*) proves to be almost identical with Ruedemann's figure 23 on plate 2, besides a slightly greater elongation of the thecæ. Of these, I have found distinctly 8 in 8 mm. of length of the branches, the latter not surpassing 25 in number. The fork-like mode of branching seems highly characteristic.

On the same slab, the type of *Bryograptus lentus* Matth. (1895, pl. 48, fig. 2) is found, appearing at first glance very distinct from that of "*Clonograptus proximatus;*" but here, too, 9 to 10 thecæ of a breadth up to .75 mm. are seen, showing the same aspect as Ruedemann's figs. 19 and 21. Moreover, this slab exhibits another crowd of branches which in part are completely identical with "*Clonograptus proximatus,*" while a few branches turned to side view show the real aspect of "*Bryograptus lentus.*" Here again, 9 thecæ are recognizable in 10 mm. of length of a branch which is 1.6 mm. thick and of the same shape as Ruedemann's fig. 15. This group of *Staurograptus* has still greater importance, since three individuals of medium size have their siculæ preserved and present the characteristic side view of Ruedemann's fig. 6. As a great many other specimens of the collection which formerly were determined as "*Bryograptus patens,*" and indeed readily conform to Matthew's fig. 4, on plate 48, really belong to nepiastic stages of *Dictyonema,*[16] a similar reference of the type of Matthew seems quite possible, but I have not seen the type specimen, and thus this explanation may still be questionable.

A few additional notes can be added to the description by Matthew and Ruedemann.

The preservation showing the thecæ in full size and the sicula is rare on examples surpassing a diameter of 5 mm. The thecæ, scarcely more or less than 9 in 10 mm. length of the branch, are sometimes irregularly exposed, 6 smaller ones being visible in 4 mm. of the distal end and 4 a little coarser ones in 4 mm. of the proximal part of the same branch. Young stages, especially when crowded together, are almost inseparable from those of *Dictyonema flabelliforme* var. *ruedemanni,* while the bryograptoid neanastic stages of *D. flabelliforme* var. *acadica* and *conferta* are easily mistaken for the "*Bryograptus lentus*" aspect of laterally compressed *Staurograptus*. The great thinness of the periderm of *Staurograptus,* which never shows such a tubulose structure or wrinkling as in the case of *Dictyonema* (compare the above), is a very remarkable fact and helpful in distinguishing these two genera. In the same respect, the

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[16] Compare Westergård (4), pl. 3, figs. 5 and 6.

more rigid characters of the mucronate apertural margin of the thecæ in *Staurograptus* may be noticeable.

Unfortunately, I was not successful in finding any remains which can be compared with "*Bryograptus spinosus* Matth." ((10), p. 269, pl. 48, fig. 3) and "*Clonograptus spinosus* Matth." ((11), p. 97, pl. 7, fig. 2), which is said to present only 8 thecæ in 10 mm. of length of the branch and a distinct "axis or virgula." Nevertheless, here, too, the identity with *Staurograptus dichotomus* seems to me not quite impossible. Nor could I observe any specimens belonging to "*Bryograptus ? retroflexus*" (Matthew (10), p. 271) or to *Callograptus* (l. c., pl. 48, fig. 5), which therefore must be at least extremely rare.

On the contrary, with an abundance of individuals there is found

Monobolina refulgens Matthew

(11) 1891. G. F. Matthew, p. 44, pl. 12, fig. 6.
(12) 1903. G. F. Matthew, Report on the Cambrian Rocks of Cape Breton. Geol. Surv. of Canada, Ottawa, p. 210, pl. 11, fig. 4, pl. 16, fig. 2.

Since generally separated valves and even broken pieces occur, nothing can be added to the careful description of the author, besides the observation that this species is seen on the same surface associated with all varieties of *Dictyonema flabelliforme* and with *Staurograptus dichotomus.*

Lingulella nicholsoni (?)

Almost the same is true of a linguloid shell, cited by Matthew in 1895 (p. 273) as *Lingulella nicholsoni* (?) and in 1903 ((12), p. 204) doubtfully called *Lingulella "lepis* Salter." The specimens of the Columbia collection usually have a length of 4 to 5.5 mm., a width of 3 to 4.8 mm. and exhibit a distinct ridge on the interior of the pedicle valve. They differ from the English type as described by Salter ((9), second ed., p. 538, fig. 11) in a relatively greater feebleness and scarcity of the lines of growth. It may be of interest to note that a very similar "*Lingulella*" of Scandinavia is referred by Brögger ((5), p. 44, pl. 10, fig. 5, from the Tremadoc shales) and by Moberg ((2), from the *Bryograptus* zone) to *L. lepis* Salter.

In addition to this detailed discussion of the *Dictyonema* fauna, a callograptoid graptolite of the upper Beekmantownian may be described, because of its interesting phyletic relationships.

Callograptus grabaui sp. nov.

Flabelliform or shrub-like, not more than 15 mm. in length and 10 mm. in width of the dendromes observed. Short, non-celluliferous, basal stem (1 mm.

long, .5 mm. wide) with terminal expansion to an adhesive bulb (of .8 mm. in width). Branches 10 to 13 in 10 mm. width, .3-.4 mm. wide, closely arranged, sub-parallel, sometimes slightly flexuose. Sicula of one specimen 7 mm. long, determinable as being a very thin tube about 1 mm. in length, with a minute basal disk .5 mm. in width. Within the first 5 mm. of the length of the dendrome, a very frequent branching, sometimes of monopodial aspect, with a common angle of 50-60° takes place. Branches of the third and fourth order are usual, those of the sixth still observable. The interspaces between the branches vary from .3 mm. to 1 mm. in width. Most of the specimens are dorsally depressed and therefore, as commonly found in sandy shales, they do not exhibit the thecæ. Only a few branches, laterally compressed, show 19 to 21 thecæ in 10 mm. of length of the branch, as sharp spinelike prolongations, quite similar to those of *Dictyonema flabelliforme* (cf. Ruedemann (1), p. 601, fig. 26). Very seldom one or the other of these apertural processes reaches the neighboring branch, joining it like a dissepiment. The periderm seems to be composed of two layers, of which the greenish external one adheres to one side of a split slab, while the black interior layer remains on the other side, distinguished by a wrinkled surface. Aside from this no striation is visible.

FIG. 1.—*Callograptus grabaui* sp. nov. (3/1)

Stratigraphic Position and Mode of Occurrence: The type specimen was sent to the Columbia Collection by Victor Ziegler, who obtained the fossil from Center County, Pa., "2000 feet from the bottom of the limestone series which are referred by Collie to the Beekmantown." [17] The animal mass is profusely scattered on the sandy surface of the thin-bedded, impure limestone.

The close relationship of this species to *Callograptus salteri* Hall and *C. compactus* Walcott is proved by the following table; it is contrasted only by the distinction of the thecæ.

	C. salteri	*C. compactus*	*C. grabaui*
Max. observed size........	17 mm.	40 mm.	15 mm.
Number of branches in 10 mm. width........	12	13	10–13
Thickness of branches.....	.5 mm.	.3–.4 mm.	.3–.4 mm.
Number of thecæ in 10 mm.	14–18	12–14	19–21
Interspaces.............	Thickness of branches.	2 × thickness of branches.	Average thickness of branches.

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[17] This zone may belong to Ulrich's Stonehenge limestone.

J. Hall, who first described *Callograptus,* laid special emphasis on the characters of the whole dendrome and as in this respect the new species, *C. grabaui* fully agrees, it must be for the present referred to this genus, even though the deviation in the aspect of the thecæ shows two divergent lines of evolution among this "genus," similar to those in *Dendrograptus, Ptilograptus* etc. The striation of the rhabdomes, which some authors regard as an important feature of the genus, is not mentioned in the early description of *Callograptus salteri* by J. Hall, while Ruedemann observed such longitudinal striations "when the thecal tubes have been pressed through the periderm." This is also entirely the case in the new species.

There are three other genera of the Dendroidea which hold a median position between *Dictyonema* and *Dendrograptus* and to which *C. grabaui* could be considered to belong. *Odontocaulis* is of quite the same shape, but occurs a little later in Ordovician and Silurian time and differs in its celluliferous stem. *Calyptograptus,* a Niagaran genus, shows independence of the main rhabdomes down to the root as an essential feature. *Rhizograptus,* in its genotype (the Niagaran "*bulbosus*"), has branches, more or less reticulated, joined or overlain by others. The dissepiments of *C. grabaui* are extremely rare, so that a position among the true *Dictyonema* would be erroneous, likewise, a union with *Dendrograptus* seems to transgress the natural and originally assumed limits of this genus, considering the presence of cross-bars and the shrub-like, or perhaps even funnel-form growth of the polyparium.

ASTOGENY OF DICTYONEMA FLABELLIFORME IN COMPARISON WITH THAT OF STAUROGRAPTUS

The collection of Columbia University contains such a number of the earlier stages of the two genera that I was easily able to select a complete series beginning with the sicula and closing with the full-grown colony and this series is now preserved in the paleontological museum. Still, only a few remarks can be added to the illuminating description of Ruedemann so far as the later stages of *D. flabelliforme,* as described by this author, deviate in some respects from the normal ones presented by "forma *typica.*" All essential features, however, fully harmonize with Ruedemann's observations.

After the formation of the sicula, marked by a short, stout initial part on *Dictyonema,* by a slender, curved one on *Staurograptus,* the katembryastic[18] series begins with the budding of the first, second and third

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[18] E. R. CUMINGS: "Development of some Paleozoic Bryozoa," Am. Journ. Science, Vol. XVII, p. 50. 1904.

thecæ. These nepiastic stages of *Dictyonema* are characterized by the large angle of divergence of the first theca, the next following tripod aspect, particularly by the 4-branch-stage fairly symmetrical and basket-like (compare figures on plate XXI), while *Staurograptus* has the first bud apically derived and mostly appressed and passes afterwards through a characteristic stage with six branchlets resting in a plane vertical to the axis of the sicula. It further exhibits a slight asymmetry because of accelerated divisions of one of the primary branches. The following neanastic stage develops not only wholly the specific features, but even some of varietal value, while nemas become rare. In *D. flabelliforme* var. *acadica,* a subsequent dividing of the co-equal four primary branches happens after this, though on one or the other retarded branch 3, 4 or even 6 thecæ may form a uniserial twig before its division. (Compare figure 2 on Plate XXI.)

The first dissepiment, being the last appearing generic feature, is developed as a rule when branches of the third or fourth order are present. Thus very often a lateral compression of the movable branches will furnish a striking bryograptoid view. The same is true in var. *conferta,* besides the fact that with the latter a monopodial dividing frequently occurs. The neanastic stages of var. *ruedemanni,* however, are characterized by irregularly crowded branching and early appearance of cross-threads, as fully described and figured ((1), plate 1, figs. 13 to 19) by Ruedemann. Beyond that, several of the neanastic specimens of this variety prove to be so much accelerated, that immediately from the sicula a thick scarcely resolvable bush of rhabdomes appears to arise in a real dendrograptoid manner of growth. Neanastic stages of var. *norwegica* and var. *desmograptoidea* do not deviate from those of the forma *typica* except in one specimen of the latter variety, which has the irregular division of the branches at a remarkably large angle somewhat accelerated.

Staurograptus dichotomus generally runs through a 5- or 7-branch-stage and the individuals of this collection turn into var. *aperta* by slow or retarded dividing of an angle of 70° to 90°.

The ephebastic stage of *Dictyonema flabelliforme* chiefly establishes the characteristic outline of the colony which is infundibutiform in var. *acadica, norwegica, ruedemanni* and *desmograptoidea,* pyriform in *ruedemanni* m. f. *conferta* and vasiform in *conferta.* It is in this stage that the essential features of variety *desmograptoidea* and *norwegica* are fully developed. Basal expansions are now more commonly found. The ephebastic stage of *Staurograptus,* relatively rare, regarding the surplus of younger individuals, shows a diminution of the angle of divergence, enlargement of the thecæ and an oblique tendency of the unsupported rhabdomes, which leads to a bryograptoid exterior.

Gerontastic features are noticeable in some specimens of *Dictyonema flabelliforme* var. *conferta,* in which the development of the main varietal feature is carried to an extreme as exhibiting a reduction of the diameter of the synhabdome on its posterior end. Very large individuals of var. *acadica* indicate an undulating shape of the rhabdome, while this is telescoped in other specimens into ephebastic and even neanastic stages.

As to the possibility of keeping distinct the young stages of *Dictyonema* and *Staurograptus,* the 4-branch-stages of the first one, which does not go beyond the declined[19] position, and the 6-branch-stage of *Staurograptus,* which gets into a deflexed or even horizontal position of the branches, are of greatest importance. A similar difference holds true in regard to *Bryograptus,* of which Westergård has recently described beautiful specimens of *B. hunnebergensis* ((4), pl. 5, figs. 10-23).

I may call attention to the fact that the *Dictyonemas* here found exhibit all features of a true epacmic genus, since this increasing period of evolution is indicated by (1) the relatively long duration and the clear distinction of the early stages, because of non-existence or at least only the beginning of acceleration of the characters; (2) the appearance of new "postspecific" features in the metephebastic age, which may become inherent ones and may be pushed back by acceleration in the descendants; (3) the fact that senile features make their appearance late and are rare, if we confine them to those which doubtless manifest a decline of the individual or the colony; (4) the fact that the genus in question maintains its position at the base of a more or less widely branching evolutional series. All these features are shown in *Dictyonema flabelliforme* from Navy Island, N. B.

On the Structure of Dictyonema flabelliforme

Though the specimens available for study were compressed upon the shale and so do not permit investigations similar to those made by Wiman, I have nevertheless been compelled to direct my attention to the points raised by these investigations, since several recent writers have spoken rather slightingly of them or have considered them open to question.

At first glance, a striking difference seems to exist between the graptolitic mass, one rhabdome exhibiting a reflecting silvery surface while others show a matt blackish one. By cautiously scraping on the best-

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[19] See Ruedemann (1), p. 485.

preserved specimens, the reflecting layer is found beneath the matt exterior, which usually adheres to one side of the split slab, the reflecting layer remaining on the counter side. If we shave the reflecting mass away, again a matt black skin can be recognized. This is apparently the same type of observation made by Frech on the graptolites of Sadewitz.[20] He states that a dark horny cover is separable from a brilliant interior layer and that the latter consists of calcite crystals. I could not get, it is true, any reaction on touching the mass with hydrochloric acid. Nevertheless, I believe that the two sheets described may represent the epidermal and mesodermal tissues of these ancient hydroid zoaria.

As to the composite character of the rhabdomes, on all better preserved branches, the wrinkled structure long ago recognized by a great many authors can easily be seen in var. *acadica* and *conferta,* while rarely observable in the other varieties. After much search, I succeeded in finding a few dendromes on which pyritization had partly taken place, so that several minute tubes about .10 mm. in width are shown in relief running along the thecæ in a slight curve (compare Ruedemann (1), p. 607, text figure 28) toward the aperture.

The terminal pores of these little tubes, however, were to be found only on one flanking branch of a rhabdome belonging to var. *acadica,* which closely resembled Wiman's *Dictyonema rarum*[21] (pl. 12, fig. 10). I was able to trace back this composite structure up to the second theca, but it was by no means recognizable either on the sicula or on any adhesive organ. That, furthermore, the wrinkling of the surface has nothing to do with any stress, is proved by the fact that a true cleavage sometimes does exist, cutting the widely scattered rhadomes on a slab in one and only one direction. It produces a very fine cross striation which, in the beginning, I was inclined to regard as a true ornamentation; but when R. Ruedemann kindly called my attention to the possibility of the other explanation, a renewed study soon brought me to accept it.

Another old observation, that below the fan-like tissue of a *Dictyonema,* the counter wall of the funnel can be obtained by careful preparation, which I always found true among my material, was elucidated in another way, because I got several specimens which had been quickly buried and compressed in such a manner that the apertural spines of the thecæ of one wall make their appearance in regular, pointed rows between the meshes of the covering side of the funnel. Very often, too, the variety *ruedemanni* has its rhabdomes so badly pressed together that it

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[20] F. Frech and F. Roemer, Lethæa geognostica, part 1, p. 570. 1880-97.

[21] Carl Wiman: "Ueber die Graptoliten," Bull. Geol. Inst. Univ. Ups., Vol. 2, pl. 12, fig. 10. 1895.

becomes rather difficult to keep those of the two sides distinct, on account of the shape and density of the branches.

Mode of Life of Dictyonema flabelliforme

Writers differ greatly in their opinion regarding the mode of life of *Dictyonema flabelliforme,* one considering it planctonic, another benthonic, but in recent years the idea of an epiplanctonic[22] life, *i. e.,* by adhesion to floating seaweed, has been introduced with success by Walther and Lapworth. Even, however, in the case of *Dictyonema,* where among the Dendroidea the epiplanctonic theory might possibly have applied, an earnest objection was raised by Wiman when he showed that *D. cavernosum* had branching stolons, partly strengthened by radial ribs, leading him, as it did Jaekel before him, to the conclusion that this species, like the "sessile denizens of the deeper regions," must have formed meadows on the bottom. Matthew found at Navy Island two mature forms, each with a distinct rootlet, and yet he made the suggestion that "possibly these processes may have had some other office than that of anchoring." Ruedemann, agreeing with him, lays special stress on the fact that all well-preserved specimens from Schaghticoke, whenever retaining more than the sicula, were provided with long thin nemas. Thus he is inclined to assume a suspended life for *Dictyonema flabelliforme,* with fixation in old stages, as unimportant exceptions. Recently, Westergård, to whom we owe the best work on the Swedish material, completely disregards the indications of what was called a "rootlet," stating that among one hundred specimens no nema and no disk has been observed in spite of distinct proximal parts exhibiting free siculæ.

With these contradictory facts in mind, when studying the Columbia collection, which fortunately preserves the two known examples of rootlets, I proceeded to investigate all the available material with the following results: Of 500 specimens part way through the first stages of growth, only 20 per cent have a well-preserved sicula, which even in ephibastic stages ends, as a rule, in a sharp point; a few specimens, most of which are not quite ephebastic, are provided with a nema as in Ruedemann's examples and I observed only three nemas up to 20 mm. in length; the younger the stages, the more individuals possess nemas; 78 per cent have a more or less broken or concealed end, about 2 per cent other basal organs.

In order to present a fair account of the last, I have tried to draw all the examples in question with most careful accuracy. (Plate XXI.)

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[22] Walther used the term pseudoplancton; the term epiplancton has been introduced by Grabau to cover organisms living on or attached to pseudoplancton.

In this connection several observations seem noteworthy.

1. Number of basal organs: var. *conferta* 2, var. *ruedemanni* and *ruedemanni* m. f. *acadica* 6, *acadica* juv. 2.

2. At least one neanastic specimen of var. *ruedemanni*, 10 mm. long, shows clearly a perfect stipe with a fringed, attaching expansion at the base.

3. Nema and stolon-like stem have the same structure. They gradually increase from .1 to .6 mm. in width and are traversed by a central canal.

4. Disks may be expanded from the nema, the stolon-like stem or immediately from the sicula.

5. When basal stipes are present, the siculæ are rarely kept distinct.

6. Budding from stolons is not an unlikely occurrence.

A few detailed observations may give confirmatory evidence. As to point 6, a young individual of var. *conferta* (11 mm. in length) has attached to the top of its sicula a small body .5 mm. in length, from which an irregularly fringed stem rises in the opposite direction, while to the left denticulated processes depart. I consider it quite possible that these denticles mark newly appearing thecæ which budded from the stolon-like stipe, as in the case of Wiman's *Dictyonema cavernosum;* but the unfavorable kind of preservation as well as the singularity of the specimen fail to furnish sufficient certainty of this explanation (see plate XXI, 1*b*).

Figs. 3*b* and 4*d* on plate XXI are the types of Matthew (1895) which belong to the variety *ruedemanni* and are crowded on the same surface with 16 other *Dictyonemas*. Only four of them have distinct proximal parts, one a simple sicula, one (see fig. 4*a*) exhibits a relatively thick stem distally broken off, the other "rootlets," the distal portions of which are not quite evident. Siculæ are lacking, apparently from being overgrown by the mass of the stem.

The individuals of figs. 3*a,* 4*b* can be explained as provided with true floating organs. The specimen of figure 4*c* is excellently preserved, therefore of particular importance.

Now, Ruedemann, though fully discussing the great probability or, as I think, necessity of the suggestion of a true sessile life in the later Dendroidea, objects ((1), p. 579) that "no cases of actual attachment and fixation have yet been recorded." Hence, I searched among modern benthonic forms provided with similar organs for attachment and believed I had succeeded, when I visited the excellent collection of the Smithsonian Institution at Washington. On the Gorgonias there exhibited, exactly the same kind of stems, partly stout and short, partly elongated and relatively thin are observable and they rise from the same terminal expansions characterized by irregular shape, fringed margins, corroborating ribs and rootlike filaments, all that as changeable as required by the nature of the point of fixation. I mention, especially, *Paramuricea borealis* (from 200 fathoms) and *Acanthogorgia armata* (from 160 fathoms), from the Gloucester fisheries. The last, a large, dendroid form, is furnished with a basal stem extending distally into a rather thin, irregularly shaped expansion which adheres by means of two dependent lobes to the rounded edge of a bowlder about four inches long. The similarity of this attaching instrument to that of the *Dictyonema* figured plate XXI, 3*b*, is of great significance. According to my opinion, the only reason that we have not yet succeeded in finding actual fixation of the Dendroidea lies in the fact that the sediments of those places on which the dendroids actually flourished were not favorable for preserving the delicate graptolites, while in the common "graptolite shales" we do not have the sediments on which the Dendroidea actually grew, an assumption strengthened by the mode of embedment discussed in the next chapter.

To get the significance of the foregoing statements, I may explain them in the following manner: Of all distinct varieties from Navy Island, those which tend to a callograptoid and dendrograptoid aspect also present the greater part of adhesive organs; these are not confined to the gerontastic stage and not separable from the nemas; the great variation of basal organs imply a similar variation of habitat.

Here, too, we must bear in mind the results of the last fifty years' work, as follows:

Supposed Cambrian ancestors of *Dictyonema*, with sicula, planctonic.

Earliest Ordovician, *Dictyonema flabelliforme;* young stages with long flexible nema and thin adhesive disk, ephebastic stages generally with free sicula, one variety sometimes sessil and that possibly beginning in neanastic stage.

Later Beekmantown, *Callograpti*[23]; free siculæ sometimes observed, particularly in young stages, later robust stems or hydrorhiza commonly occur.

Later Ordovician and Silurian, *Dictyonemas;* no nema and almost no trace of a free sicula observed; on *D. cavernosum* branching stolons with buds; on the whole, 12 species[24] are known provided with organs adapted for constant fixation. *Odontocaulis;* robust main stem, from which new thecæ arise. On almost all other genera of the Dendroidea, especially *Dendrograptus* no free sicula known, an abundance of organs of attachment described.

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[23] Compare *C. salteri, grabaui, elegans, radicans.*

[24] *Dictyonema arcyi, bohemicum, cavernosum, crassibasale, desmoidea, leroyense, parallelum, percrassum, polymorphum, subretiforme, stenactinotum, tenellum.*

I cannot help feeling that all these facts urge the conclusion that in the history of one large part of the ancient hydroids, there was one route of evolution prescribed, namely: The change of habitat starting from a holoplanctonic and passing through a partly epiplanctonic to a definitely sessile mode of existence.

ON THE OCCURRENCE AND STRATIGRAPHICAL RANGE OF THE VARIETIES OF DICTYONEMA FLABELLIFORME

Because, fortunately, large slabs up to a size of 2 square feet were collected, I was enabled to attend to the association of the *Dictyonema* faunula. This is imbedded in an extremely homogeneous, highly carbonaceous black shale of finest grain. Small concretions of iron pyrites are frequently scattered over the surface, though infiltration of the fossil material is rarely to be found. The more profusely the animal mass lies buried in the slates, the thinner they split. Cleavage of any considerable amount rarely appears, though often recognizable in minute pseudostriation running in the same direction over all rhabdomes of a slab. The slates are exactly of the same character as those of the *Diplograptus geminus*—zone (Llandeilo) from Fogelsång (Skåne, Loc. E 5 of No. 40 of the Guide of the International Geol. Congress, 1910), those of the Upper Graptolite-shale (Tarannon) from Stommen (Westergoetland) or those of the upper Hartfell-shale (Caradoc) from the Moffat district (zone No. 8, South Scotland), except that most of the European occurrences have been a little more affected by stress.

Two different kinds of embedment can be noticed. Slabs on the surface of which single specimens with remarkably fine preservation are found, accompanied by clusters of early stages, alternate with others which are completely covered with a pell-mell of fragments and individuals, often almost indeterminable and lacking any favored direction. Here the variety *ruedemanni* and *Staurograptus* are extremely common. On a single slab 1.5 feet square, I numbered more than one hundred neanastic and ephebastic dendromes, omitting the rhabdomes pieced. As a rule, both sides of the colony are closely pressed together without any interbedded layer of mud, a strong evidence of rapid sedimentation, caused by rough and sudden events. On the contrary, the slabs of the first-described mode frequently show a rather thick sheet of mud inserted between the walls of the dendrom. Sometimes this is imbedded at a distinct angle of up to 5 degrees, found between the axis of the colony and the surface of the split shale which is likely to be caused by the weighing down of the heavier, distal end of the body. A rather slow deposition has to be assumed in these cases.

As a matter of special interest, but also of insufficient evidence, the strange arrangement of several specimens around a common center demands careful attention. It was originally figured by Salter and Goeppert. Afterward, however, it was questioned by the majority of authors, but was recently again mentioned by Fearnsides ((3), p. 307) and I likewise have observed some examples, particularly of early stages which can be classed herewith. Fig. 1*a* on plate XXI presents two *Dictyonemas* opposite each other, each of them attached to a minute common disk. Fig. 2*c* shows two young individuals joined to each other by means of their proximal parts. I observed also four full-grown specimens of the variety *acadica* m. f. *ruedemanni*, uniting as appears in the text-figure 2. In all the examples studied, no nema and only once a common disk is present, so that an immediate fixation by the basal parts of the colonies must be assumed. If this is the fact, which I am rather inclined to hold on account of the specimen discussed, a colonial arrangement of the third order possibly existed comparable with that of *Diplograptus pristis*.

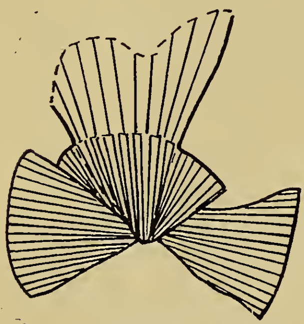

FIG. 2.—*Dictyonema flabelliforme* var. *acadica* m. f. *ruedemanni* (1/1)

The statements thus far made about the association of the faunula with *Dictyonema flabelliforme* do not vary to any considerable extent, provided that we will except the fossils gathered from interbedded limy nodules ("orstensbollarne"). G. F. Matthew[25] pointed out that in the Dictyonema-shales of New Brunswick, two bands (b, c) are distinguishable, namely, a lower one with var. *conferta* as the predominant type besides var. *acadica* and a higher one containing an abundance of the var. *acadica* and also var. *norwegica*. At Navy Island, both zones furnish the "Bryograpti" and a few brachiopods, the latter being better represented on the section of McLeod brook. In the slate belt of Eastern New York, Ruedemann,[26] though not able to fix the relative position, again recognized the *Dictyonema* bed separated from the *Staurograptus* bed, which also contains *Dictyonema flabelliforme* var. *acadica*, together with several species of brachiopods, identical with those of Matthew. As to the European occurrence, the best recent explorations were made by Moberg (2) and Westergård (4), who generally agree with each other

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[25] See references (10), (11), (12) and "On a New Horizon in the St. John Group," Can. Rec. Science, Vol. 4, No. 7, p. 339. 1891.

[26] Cf. footnote No. 15.

in keeping distinct the lower level of *Dictyonema flabelliforme* forma *typica* which is accompanied by *Obolus salteri* and *appolinis* and a large *Lingula ? corrugata,* and the higher zone of *Bryograptus kjerulfi,* which has associated with it *Clonograptus tenellus, Dictyonema norwegicum* and *Lingulella* cf. *lepis.* It is Westergård who interpolates between them a separate zone of *Clonograptus tenellus* and *Bryograptus hunnebergensis.* My own observations harmonize with these statements in a quite satisfactory manner, for I found that occasionally individuals of all described species and varieties were met with on the same slab; that, however, in one part of the collection studied, *Dictyonema flabelliforme* var. *acadica* and var. *conferta* prevailed, associated with *Monobolina refulgens,* while, in another part, *Dictyonema flabelliforme* var. *ruedemanni* was mixed with var. *acadica, norwegica, desmograptoidea* and *Lingulella ?* cf. *lepis,* but that in both cases *Staurograptus* occurs frequently. Although, of course, I am not able to make any statements about the relative age of these two beds, the close conformity of the facies on both sides of the Atlantic, when considered in a general manner, seems to me to urge the assumption of homotaxial relationship, provided we are willing to hold to the slight faunal differences due to the geographical separation, for the supposed evolution of the *Dictyonema* follows exactly in the same order as the historical succession. Hence, the identification of Matthew's zones with the two lower beds of Westergård seems, according to my opinion, to be correct.

Significance of the Varietal Range and its Phylogenetic Value

Before balancing the observations on the Navy Island faunula, some general questions bearing on the zoölogical point of view must be discussed. The first one has to deal with the term "variety," applied to the observed changes of *Dictyonema flabelliforme.* The following points come into consideration: The features in change are not only confined to one or the other character of *Dictyonema flabelliforme,* but, as shown by the diagram and textfigure 3, every feature of specific, even of generic value is subjected to a more or less extended change. While a small part of the observed varieties are mostly restricted to later stages of *Dictyonema flabelliforme,* in some cases, *e. g.,* var. *ruedemanni,* and *desmograptoidea,* a considerable telescoping of the varietal features appears, which thus have already become inherent. Furthermore, not all of these varietal features are interchangeable; for instance, links between var. *ruedemanni* and var. *norwegica* never occur. On those links, however, that are found, even new crossing features are observable (pyriform shape of var. *ruedemanni* m. f. *conferta*). That this variability is of rather important value is illustrated by the fact that the same features which characterize the varieties are to be met again, somewhat further developed and more distinctly separated, in later genera, *e. g., Callograptus, Dendrograptus,* so that these features have true orthogenetic significance.[27]

Considering only this point of view, we could come to the conclusion, as did Moberg in 1906, that these modifications are useful for specific separation. We must bear in mind, however, that all the varieties start from a common center, *i. e.,* var. *acadica* = forma *typica* of the European localities; that, therefore, an unbroken chain of bridging types exists which embrace all the different forms which elsewhere, when isolated, were scarcely regarded as being in any way related one to another.

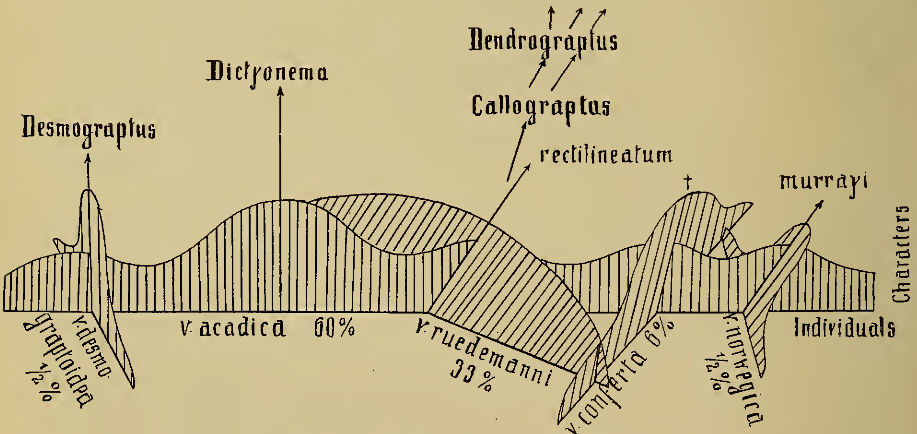

FIG. 3.—Range of variability of *Dictyonema flabelliforme*

Finally, any separation by time is significant only between the var. *conferta* and most of the other varieties, which all have apparently grown together. For the separation of types, I regard the foregoing as of varietal, but not of specific or mutational value. For this last, we may regard either the saltative character or the interval of time as the essential point.

As to the cause of those changes, we may find it by starting from a mechanical point of view. How do sessile organisms react to a more or less continuous pull? If the pull is small, there results elongation of

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[27] The constantly increasing number of Dendroidea, found in the Ordovician of North America, as compared with their sporadic appearance in European localities, makes it probable that the continuous evolution was more likely confined to the American seas.

the organs combined with elasticity and flexibility; if the pull is too great, only concentrated forms may exist. Near the boundary line of the trees of Alpine regions, we find species with slender, movable branches (*Betula, Larix*), while in places relatively protected from storms, we find dwarf trees and bushes, low and closely clinging (*Pinus, Picea*) or extremely thickened stems on the slopes of hills exposed to windy squalls. Water-plants lengthen their stalks or build a concentrated mass according to their standing places. And the same reaction must be true in benthonic animal life. The whole dendrome of *Dictyonema* was subjected to the pull in water, *i. e.*, the mechanical stress exerted against the fixed body by the action of currents, waves and breakers and thus the animal mass proves to be influenced.

As a result of this we have:

I. Var. *acadica*. This middle type of all the varieties shows very great progress over the small bryograptoid ancestors of *Dictyonema*, as is proved by the neanastic and nepiastic stages, for the elastic cross-threads enable single branches to grow to such an extent that, for example, a colony 160 mm. long could have 20,000 theca and yet have sufficient firmness for existence.

The varieties given here show the complete possibility of improvement, but that *acadica* has not reached the highest place is proved by the fact that of all perfectly preserved examples of later ephebastic stages, *acadica* has less than 10 per cent, the pyriform paratype up to 50 per cent, *ruedemanni* up to 50 per cent, *conferta* 70-80 per cent, *norwegica* less than 10 per cent, *desmograptoidea* less than 10 per cent.

Forms like *acadica* take the middle line of all true *Dictyonemas* through the Silurian, Devonian into the Carboniferous (compare *retiforme, scalariforme, stenactinotum, spenceri, leroyense, brairi*).

II. Var. *norwegica* endeavors to progress by a heavy thickening of the rhabdome net, but it causes great weighting down of the body and much profusion of organic matter, so that this mode of building up will be possible only when food is abundant. Compare *D. quadrangulare, murrayi, crassum, arayi.*

Result: A few sporadic species up to Devonian time; no generic evolution; one-half of one per cent of our forms, more or less broken in pieces.[28]

III. Var. *desmograptoidea* has closer and even elastic branches joining with fewer cross-threads.

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[28] Also Westergård mentions the scarcity of unbroken specimens of this variety (4), p. 60.

Result: Through forms like *irregulare, homphrayi,* generic evolution into *Desmograptus* up to Devonian; one-half per cent of our forms, because of somewhat later starting of evolution.

Good stolon in later species, sessile; finally, thinning of rhabdomes (*tenuiramosus,* a sessile pseudo-*Dendrograptus*).

IV. Var. *ruedemanni.* Heavy branching and a successive diminution of the elastic cross-threads produce a thick brush and dense crowding of nourishing thecæ, while still allowing movement of the rhabdomes.

Result: 35 per cent of whole fauna; 50 per cent perfectly preserved.

Half of the observed attaching organs belong to this variety. Evolution: (*a*) persistence of type in a few Ordovician and Silurian species; stolons and roots common. Compare *delicatulum, perexile, rectilineatum, subretiforme, tenellum, filiramum.* (*b*) Further reduction of cross-threads, enforced reduction in size. Intermediate forms: *Callograptus, Rhizograptus, Odontocaulis, Callyptograptus;* sessile, in early stages vagrant; then *Dendrograptus;* stolons and roots. Further evolution of *Dendrograptus* leads to thin flexuose types (*i. e.,* under slight pull) or to succulent types (*i. e.,* under heavy pull); latter forms sometimes with central axis. End of this evolution: *Ptilograptus, Acanthograptus,* etc.

V. Var. *conferta,* cylindrical growth and close network, giving mechanically the best type.

Result: On one side 6 per cent of our forms and 70-80 per cent perfectly preserved; on the other no specific evolution at all, probably on account of very unfavorable conditions of food supply.

VI. Last type of change by thickening and dividing of the cross-threads (groups of *peltatum, cervicorne, cavernosum, tuberosum*) not represented in our fauna. Appears first in American Ordovician. Stolons and roots well developed.

Considering this mechanical starting point, it becomes of interest that the Gorgonias of equivalent habitat (disregarding the funnel shape of the *Dictyonema* colony) present the same lines of changes as those sketched in the foregoing for *Dictyonema flabelliforme.* Thus we find among the *Leptogorgias, L. eximia* and *media* with a network like that of var. *acadica, Leptogorgia agassizi* with close fine meshes comparable to those of var. *conferta,* while *Leptogorgia rigida* looks like a callograptoid type and *Eugorgia multifida* like a *Dendrograptus* with beginning central axis. The latter, still further developed, gives *Pterogorgia acerosa,* while *Gorgonia flabellum* has a typical desmograptoid appearance and *Gorgonia quercifolia* resembles closely the *norwegica-murrayi* line. I cannot help thinking such a conformity indicative of parallelism in evolution and that it represents one of the usual lines of development of such benthonic forms under a given environment.

Now, with all the foregoing statements, we may touch upon the final question of the *phylogeny* of the dendroids as indicated by the range of variation in the earliest *Dictyonema.* A certain branch of the planctonic ancestors common to both Graptolites and Dendroidea was evidently pushed forward in the lines of directed evolution by the formation of dissepiments as a supporting mechanism of the elongating rhabdomes. This represents the *Dictyonema* stage, beyond which a group of retarded species and genera (*e. g., Desmograptus*) never passed to any considerable extent. While in the *Dictyonemas* of the early days, fixation was realized only by means of a thin, fragile nema, the adhesive organs were now brought into vital and ever increasing significance. For gradually thickened stems with basal expansions, with stolonial ramifications, with ability of independent budding of thecæ and of colonies, were built, while the original planctonic period of life becomes shortened to its final disappearance (*Dendrograptus*-stage). From this point on, an extreme widening of the main stipe, on one side, gave rise to the *Galeograptus, Discograptus, Cyclograptus, Rodanograptus*-group, while a thickening of the central axis led to forms like *Inocaulis, Acanthograptus, Cactograptus, Palædictyota,* to which even *Chaunograptus, Corynoides* and *Thamnograptus* may be related, as held by Ruedemann. Finally, in types like *Mastigograptus,* a striking approach to the present hydroids has been revealed. When considering the various races of Dendroidea on such a broad basis, the various genera do not of course mean anything else than stages in development; and every line of separation seems an arbitrary one, as is shown in a comparison of the species thus far assigned to "one genus" by the different authors (*e. g.,* the *Callograpti* and *Dendrograpti*). Nor is the difference between the forms in the early Ordovician with free siculæ and those with unknown siculæ a reliable one upon which alone to base the natural classification.

Within the last five years, two papers of such importance regarding the differentiation and evolution of the *Dictyonemas* have been published that they must be considered with great care. In 1907, W. S. Fearnside (3) made some striking suggestions. He believes that

> "in the earliest *Dictyonema,* the cells are very indistinct and rarely project more than about a quarter of the diameter of the common canal; cross-threads thin and numerous; stipes close together, parallel, branching at all levels; elongated rectangles of meshes. This supposed *Dictyonema* diverges in two distinct families, one approaching the true graptolites (*Dictyograptus*), the other seems more nearly related to the Dendroids (*Dictyonema, sensu stricto*).

Dictyograptus	*Dictyonema*
"Cells: Well-marked; tend to become uniserial.	"Cells: Small, generally disposed at angles of about 120°. Crinkly longitudinal ornament appears.
"Shape: Like a fisherman's net from a sicula of no great length with primary branches, diverging at an angle rarely greater than 90°.	"Shape: Basketlike, starting from a long narrow tube or nema and diverging at angles which in the later forms approach 160°.
"Dissepiments: Their development ever more and more delayed until they become practically abortive.	"Dissepiments: Their importance, increase and the general aspect of the later forms is that of a square or rhomboidal mesh in which cross bars and stipes are of approximately equal importance.
"Type: var. *acadica* forma *typica*."	"Type: var. *norwegica*."

There is one point in which I completely agree with this author, viz: the importance of the differentiation among *Dictyonema flabelliforme*. We both believe in this as the point of generic divergence; but in detail, I cannot help stating that all my observations run along the opposite direction. I merely recur to the facts that

Var. *conferta*, restricted to a lower horizon, according to the suggestions of Matthew, Fearnside and the majority of the Scandinavian authors, shows clearly the tubulose structure and mode of growth and dissepiments of *"Dictyonema"* and the projecting cells of *"Dictyograptus."*

Var. *desmograptoidea* has cells, mode of growth like *"Dictyonema,"* cross-threads like *"Dictyograptus."*

Var. *acadica* has cells, sicula, like *"Dictyograptus,"* tubulose structure like *"Dictyonema."*

Var. *norwegica* has cells like *"Dictyograptus,"* dissepiments like *"Dictyonema."*

Var. *ruedemanni* has sicula, dissepiments, structure like *"Dictyograptus,"* cells and growth like *"Dictyonema."*

Hence, as all the known varieties are in part distinguished by the features of *"Dictyonema"* and in part by those of *"Dictyograptus,"* such a separation, of course, seems impossible. Furthermore, the ancestors were doubtless bryograptoid with very distinct cells, without numerous dissepiments. Nor did Westergård agree with Fearnside's assumption, so that against this hypothesis there appears to be no further objection necessary.

On the other hand, Westergård, from whose detailed work my own observations do not differ widely, starts with the following suggestions:

Among a hundred examples of *Dictyonema flabelliforme* examined, he failed to observe nemas or disks or any adhesive organs in spite of distinct proximal parts with free siculæ. He regards the wrinkling of the rhabdomes as produced merely by pressure, and the early appearing divisions of the nepiastic thecæ as due to rapid budding of nourishing thecæ. He holds it probable that the early Dendroidea like *Dictyonema flabelliforme* when derived from graptolites must have possessed thecæ like those of *Bryograptus kjerulfi.* From this point on, he considers that there existed a great difference between the *Dictyonema flabelliforme* and the *"Dictyonemas"* of the later Ordovician and Silurian, as described partly from sections by Wiman and others, and he introduces *"Dictyodendron"* for the later forms.

The following objections, however, must be made after careful consideration: 1. Young individuals of *Callograptus* (*salteri* in Ruedemann's monograph, *grabaui* as described in this paper) exhibit distinct siculæ and even nemas. 2. True adhesive expansions occur among the *Dictyonemas* of Navy Island. 3. The tubulose structure is by no means referable to any kind of stress, because this, when exerted, produces a fine striation, running in parallel fashion over all specimens of one slab, but cutting, of course, the tubes at quite different angles. The associated *Staurograptus,* moreover, never show a similar structure. 4. The young stages of *Dictyonema flabelliforme,* as fully discussed in the foregoing, are found to be clearly distinct from all stages of *Bryograptus,* as they exhibit a more primitive character (dependent growth) than *Bryograptus* (declined or horizontal growth of the first branchlets). Hence the ancestors of *Dictyonema flabelliforme* were not at all true *Bryograpti,* but simpler types with features bridging over those of *Dictyonema* and *Bryograptus.*

Thus I feel quite certain that the progress of evolution which Westergård believes to have existed between the early *Dictyonema flabelliforme* and the so-called *"Dictyodendron,"* did really take place among the varietal series of the *Dictyonema flabelliforme.*

Finally, there is one point left which thus far I have deliberately disregarded in order to simplify its consideration, for it adds merely some complications without modifying the preceding conclusion. There is no doubt of the fact that most of the dendroid genera have the characters not only of stadial, but also of collective groups. Of this James Hall was partly convinced even in the '60's, but it has only been recently fully substantiated by the masterly works of Wiman and Ruedemann. Among the *Dictyonemas,* one part has thecæ with sharply prominent lips, another possesses obscure pits and grooves in place of thecal apertures; one group is distinguished by an uniserial, the other by a biserial arrangement of the thecæ; a few species belonging to widely separated divisions are proved to be heterothecal, while others are strongly suspected to be homœothecal.

We find similar differences among the genera of Callograptoid appearance, particularly among the *Dendrograpti,* the *Ptilograpti* and in the *Galeo-Disco-Cyclograptus* group. Those differences are not confined to a certain geological age. Early as well as later species may show the same kind and arrangement of the thecæ, while congeners reveal the difference as great as possible in this respect, *e. g.,* the highly variegated Niagaran dendroids of America. This difficulty of a heterogeneric but parallel evolution seems still further increased in complexity by the repeated development of features either retrogressive or intermingled. For we observe the strongly differentiated genus *Dendrograptus* already at the base of the Ordovician (if not earlier) and yet we see that the path of varietal evolution is in the same direction in much later strata. We observe true *Dictyonemas,* the neanastic stages of which suggest certain ancestral relationship to members of the *Desmograptus* or the *norwegica-murrayi* group. That the same is true among the Callograpti is proved by a comparison of Počta's, Bassler's and Ruedemann's species herein referred to. Even the characteristic bifurcation of the apertural margins and dissepiments has now been found in quite different species and genera, *e. g., Ptilograptus,* a very doubtful and not unlikely retrogressive genus, to which some *Callograpti* described by Počta bear an undeniable similarity.

However complicated the paths of evolution of the Dendroidea may be, paths which can be traced back only after the manner of Wiman's and Ruedemann's keen-eyed and careful investigations, I am convinced that, generally speaking, they followed directions similar to those manifested pre-figuratively in a small but equivalent ratio by the range of variation in *Dictyonema flabelliforme.*

PLATE XX

RANGE OF VARIABILITY IN DICTYONEMA FLABELLIFORME AND ITS EVOLUTIONAL SIGNIFICANCE

Varieties of *Dictyonema flabelliforme* and *Callograptus grabaui* n. sp. correctly drawn after actual specimens in the collection of Columbia University; other species and genera sketched after Hall, Ruedemann and Wiman.

(Reduce all given magnifications by three-fourths.)

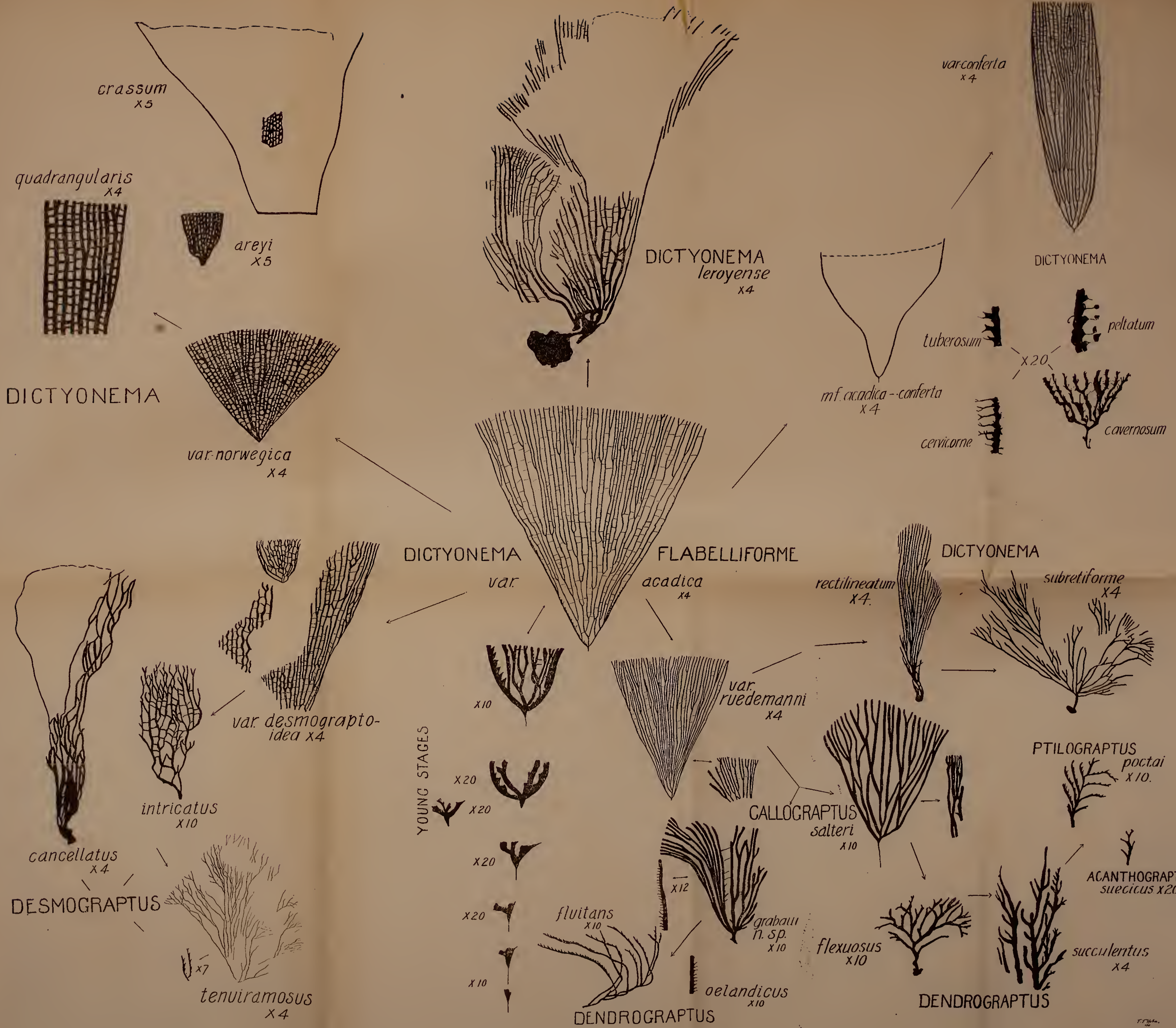
crassum
x5
quadrangularis
x4
areyi
x5
DICTYONEMA
var. norwegica
x4
DICTYONEMA
leroyense
x4
var. conferta
x4
DICTYONEMA
mf. acadica -- conferta
x4
tuberosum
peltatum
x20
cervicorne
cavernosum
DICTYONEMA
var.
FLABELLIFORME
acadica
x4
DICTYONEMA
rectilineatum
x4.
subretiforme
x4
cancellatus
x4
DESMOGRAPTUS
intricatus
x10
var. desmograptoidea x4
x7
tenuiramosus
x4
YOUNG STAGES
x10
x20
x20
x20
x20
x10
var. ruedemanni
x4
CALLOGRAPTUS
salteri
x10
x12
fluitans
x10
grabaui
n. sp.
x10
oelandicus
x10
DENDROGRAPTUS
flexuosus
x10
PTILOGRAPTUS
poctai
x10.
ACANTHOGRAPTUS
suecicus x20.
succulentus
x4
DENDROGRAPTUS

PLATE XXI

BASAL ORGANS OF DICTYONEMA FLABELLIFORME

1 *a*, *b*, var. *conferta*
2 *a*, *b*, *c*, *acadica* (*b*, *c*, juv.)
3 *a*, *b*, *acadica* m. f. *ruedemanni*
4 *a-d*, *ruedemanni*

All specimens are preserved in the collection of Columbia University and are enlarged five times in the figures. The measurements given refer to the length of the entire colony, which is not always represented.


2cm
2a
2.5cm
1a
11mm
1b
4cm.
3a
8mm.
2b
6.5cm
4a
4cm.
4b
3b
8.7cm.
35mm.
2c
4d
7.7cm.
1cm.
4c

PLATE XXII

TABULAR COMPARISON OF THE SPECIES OF DICTYONEMA, DESMOGRAPTUS AND CALLOGRAPTUS

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Names	Shape and size	Length to width	Per cent of individual	Rhabdomes			Dissepiments			Thecæ		Basal organs	Notes			
				Number in 10 mm.	Character	Diverg. of branches	Number in 10 mm.	Character	Meshes	Number	Character		Passing into	Char. of stage	Evolution and age	Preservation
Dictyonema flabelliforme v. acadica	infundibuliform and pyriform large—very large	1.6:1 .9:1	60%	9–10 (8–12)	.4 (.3–.5) mm. subparallel	45° 80°	4–5 (3–8)	thin .2 mm.	quadrang. (elongated)	16 (15–17)	projecting	sicula, nema ? 1 stolon (young stage)	conferta norwegica desmograptoidea ruedemanni	early stage bryograptoid late stage with mixed features	center of variability true Dictyonemas up to lower Carboniferous	90% of later ephebastic stages broken
brairi	infundibuliform medium size	.8:1 (?)	....	8–10	.4 mm. subparallel	± 45°	4–5	.25 mm.	quadrang.	.....	....	....	......	......	last known species lower Carboniferous	broken
leroyense	infundibuliform large ?	1:1	....	8–10	.6 subparallel (desmoid)	45° 80°	2–4	.25 mm.	subquadrang.	.....	....	basal adhesive disk	......	neanastic with thickened branches	Onondaga	broken
v. conferta	vasiform—cylindrical medium size (large)	2.5:1 (3.7:1) (1.5:1)	6%	8.5–10	.4 (.3–.5) mm. subparallel—parallel	45° 70°	7 (6–8)	thin .1–.2 mm. regular	quadrang. (regular)	17 (16–18)	delicate projecting	sicula, 1 basal disk ? 1 branching stolon	acadica ruedemanni (pyriform link)	early stages: bryograptoid; late ephebastic contraction	not any evolution	20% of later eph. stages
v. norwegica	infundibuliform large	.9:1	½%	8–10	.5–.7 mm. robust ± parallel	50° 90°	6 (4–8)	thick—irregular (.1)–.6 mm.	rectang. subcircular	15	robust acute	....	acadica (conferta)	char. of var. usually restricted to late stages of acadica	a few species in Ordovician; parallel evolution up to lower Devonian	broken
murrayi	? large	?	....	4	1.5 mm. stout parallel	50° 90°	4	rigid .4–.9 mm.	rectang.	9–10	acute	....	......	......	Beekmantown	± broken
crassum	infundibuliform large	1:1 (?)	....	9	.5–1 mm. stout ± parallel	50– (90°)	4–5	irregular .4–.9 mm.	rounded subquadrang.	.....	....	....	......	distally desmograptoid	New Scotland	± broken
v desmograptoidea	infundibuliform medium size	1:1	½%	8 (7–9)	.4 mm. subparallel—flexose—joining	± 90 (45°–90°)	3–4 (1–5)	very irregular .1–.4 mm.	irregular subovate	15	delicate less projecting	....	acadica	char. of var. usually restricted to late stages of acadica; acceleration beginning	to genus Desmograptus, up to middle Devonian	± broken
intricatus Desmograptus	infundibuliform medium size	1:1	....	15–20	.1 mm. flexose (thin) coalescent	45°–90°	(0–1)	very rare irregular	elongated subovate	.....	appressed circular	sicula ?	......	basal parts with Dictyonema character	Chazy	± well preserved
cancellatus	infundibuliform medium size	2:1 (?)	....	12–14	.8 undulating (thick) joining	± 90°	(0–1)	very rare irregular	elongated subovate	frequent	appressed circular	chitinous basal expansion, short stem	......	......	Beekmantown ?—Chazy	± broken
v. ruedemanni	infundibuliform—pyriform large—very large	.7:1 (.63:1) (1.1:1)	33%	12 (10–15)	.35 subparallel	± 45°	3 (1–5)	thin—irregular .1 mm.	quadrang. elongated	15–16	delicate	sicula, nema or stolon with disk, branching stolon in neanastic stage	acadica conferta (pyriform link)	early stages with acceleration; old stages partly callograptoid	similar species up to Devonian further coolution into Callo- and Dendrograptus	40% or less broken
rectilineatum	? medium size	?	....	12–14	.4 subparallel—parallel	± 45°	3–5	irregular —.16 mm.	quadrang.	.....	irregular	? short stem	......	old stages partly desmograptoid	Chazy	broken
gracile	cyatiform medium size (large)	1:1 (?)	....	10–12	.4 (.6 at the base) subparallel	45° 70°	1–4	delicate irregular .1 mm.	quadrang. elongated	13–14 (20?)	projecting	basal stem and disk	......	......	Niagaran	partly well preserved
salteri Callograptus	infundibuliform small—medium size	1:1	....	14–15	.3–.5 subparallel (flexose)	± 45°	0(–1)	very few	....	14–18	irregular appressed	thin hydrorhiza	......	partly dendrograptoid	Beekmantown—Chazy	partly well preserved

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METAMORPHISM OF PORTLAND CEMENT

BY

Albert B. Pacini

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METAMORPHISM OF PORTLAND CEMENT[1]

BY ALBERT B. PACINI

(*Read before the Academy, Part I on 8 January, 1912; Part II, 1 April, 1912*)

CONTENTS

PART I

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[1] A thesis submitted in candidacy for the degree of Doctor of Science at New York University, 1912.

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Part II

PART I

Introduction

The important field of investigation covering the changes which take place in the setting and hardening of Portland cement and in Portland cement which may be considered to have attained the greater part of its maximum hardness calls for the services of experts in various branches of science. Many of the general problems can, as a whole, be relegated to the petrologist and hydrologist; and this paper is an attempt to treat cement as a rock, differing from other rocks only in being artificial, but subject to the same internal and external influences as other components of the earth's crust.

A training in geophysics and geochemistry is, perhaps, the most valuable asset in surveying the field of Portland cement. If no other end is achieved by the following pages, the mere representation of the question as a problem in applied petrology will, it is hoped, help future investigators in a more systematic inquiry.

Part I of this paper is devoted to a necessarily brief review of the present status of the subject, and no attempt is made to discuss data quantitatively. Experimental results in elaboration of the various points discussed are presented in Part II.

The experiments described in Part II were made at the laboratory of the New York Board of Water Supply by the writer, and in part by his associates, in the course of the investigations of the Board. The most modern and complete equipment was available, thanks to the prudent foresight of the gentlemen at the head of this great engineering enterprise. The data are reproduced by permission from the periodical bulletins of the Inspection division and from the annual report of the Board for 1911.

Nature of the Problem

Portland cement is a finely ground artificial rock, whose essential constituents are silica, alumina and lime. In it are found a number of component minerals recognizable by definite optical properties, but the individual constitution of which is not yet clear. The percentages of these minerals vary somewhat according to the method of manufacture and the purity of the raw materials, but there is, on the whole, a fairly stable proportion in a series of normal cements.

The method of manufacture of Portland cement will not be discussed here further than to state that it consists essentially of the calcination of a mixture of calcareous and argillaceous rocks at high temperatures. Usually, about 2 per cent of gypsum or of plaster of Paris is afterwards added to retard the set. By varying the proportion of these rocks, the temperature and duration of calcination, the fineness of grinding, and also by the addition of foreign substances products are obtained having a wide range of hydraulic properties.

The hydraulic properties are setting and hardening. Setting is the attainment of rigidity by the plastic mixture of cement and water and begins immediately after mixing, requiring several hours for completion.

Hardening is the progressive increase in strength acquired by the mass, and it attains the greater part of its ultimate value in about a year. Even after this period it is subject to a small progressive increase (42)[2].

In general the properties of setting cement are to be found both in mortars, or mixtures of cement and sand, and in concretes, or mixtures of cement, sand and broken stone, these chemically inert materials added to the cement exerting a physical influnce on metamorphism.

Chemical Composition

The chemical composition of normal Portland cement is shown in the following tables:

Average of 300 Normal American Portland Cements, Representing 20 Brands of All Types

(Analyses by the writer for the Board of Water Supply)

	Maximum	Minimum	Average
SiO_2	25.89	19.85	22.70
Fe_2O_3	4.08	1.23	2.73
Al_2O_3	9.16	3.43	6.17
CaO	64.91	59.06	62.67
MgO	4.00	0.30	2.19
SO_3	1.75	0.84	1.37
CO_2, H_2O, alkalies	.....	.....	2.17

Average of 100 German Portland Cements

(Burchartz, (12))

SiO_2	20.87
Fe_2O_3	2.98
Al_2O_3	7.63
CaO	62.99
MgO	1.55
SO_3	1.85

The ultimate chemical composition of a cement is only, however, a rather indirect clue to its hydraulic properties, just as the ultimate analysis of a composite rock may only give a faint idea as to its constituent minerals or possible products of metamorphism. For example, it would be quite possible to synthesize a mixture which would, on analysis, correspond exactly to the chemical composition of an excellent Portland cement, yet which, when gaged with water in the ordinary way, would develop practically no tensile strength, in fact would possibly fail to set at all.

Cement, therefore, must owe its hydraulic possibilities to a particular grouping of its constituent compounds, quite analogous to a series of

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[2] Numbers in parentheses refer to the bibliography at the end of this article.

minerals; and looking to the identification and classification of these minerals, a great deal of investigation has been done.

By trial burnings of simplified mixtures, such as lime-silica melts, and by microscopical examination of sections of the resulting clinker, the problem is gradually being clarified, but, owing to its great complexity, much controversial literature thereon has been issued on both sides of the Atlantic (52, 69, 80, 64, 65, 88). The theories put forth have so far had little practical effect upon the manufacture and composition of the commercial product (63).

No complete and final enumeration of the chemical compounds resulting from the burning of such a mixture of clay and limestone has yet been accepted as authoritative. The microscopical identification of the individual chemical compounds which go to make up the mineralogical entities is at best somewhat unsatisfactory, especially because of the minuteness of the particles of raw materials necessary to secure thorough and uniform calcination, and consequently the extremely small size of the resulting crystals and aggregates. It has been proposed, in this connection, to secure these of a size available for study by the expedient of fusing the clinker in an electric furnace; and, by this means, a partial clarification of the system has been obtained (103).

Mineralogical Constitution

The minerals which are recognized in cement clinker have been named alit, belit, felit and celit (101), and a metamorphism[3] of these occasioned by the action of water is the cause of the setting and hardening of Portland cement.

Alit has been reported a solid solution of tri-calcic silicate in tri-calcic aluminate, and celit a solution of di-calcic aluminate in di-calcic silicate (61). Other investigators have reported alit and celit to be silicates of different silicic acids (26).

Belit is probably a calcium aluminum silicate of the composition $Ca_3Al_2Si_2O_{10}$, a form found in nature as the mineral gehlenite (27).

Setting Process

Precisely what chemical reactions and physical transformations take place in the setting and hardening processes is not yet definitely settled. It may, however, be stated that by modifying the proportions of clay to limestone through a certain range, we obtain a product which varies in its speed of setting and of hardening. In general, cements high in silica

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[3] Metamorphism: Any change in the constitution of any kind of rock, Van Hise (104).

are found slow setting and slow hardening, while those high in alumina are quick setting and quick hardening. An increase of lime in the latter retards the setting (63).

The calcium aluminates are probably the main factors in the setting of cement, while the hardening is due to the calcium silicates. The magnesium compounds are inessential to the hydraulic processes (105).

Upon the addition of water to cement, the equilibrium in the system of solid solutions and chemical compounds is destroyed, and a series of changes is inaugurated tending towards the production of a system which will be stable under the new conditions. The first effect resulting from the solutions and reactions brought about by the presence of water is the setting of the plastic mass.

Under ordinary conditions of practise, the quantity of water used is about 22 per cent in the case of a neat cement, being less in the case of a mortar, and still less in the case of a concrete. When this proportion of water is used, it is probable that the setting of cement is mechanically analogous to the setting of plaster of Paris and is caused by the growth throughout the mass of a network of crystals, deposited from the saturated solution formed by the first stage of hydro-metamorphism.

Owing to the low solubility in water of the original component substances, the attainment of final equilibrium is a matter of considerable time, and is further delayed by the automatic protective action of films of insoluble substances coating the active particles (23). These films in some cases are semi-permeable, and exert a selective influence upon the solutions osmotically penetrating them. Under normal conditions, that is under those conditions which have been found in practise to yield the densest and strongest product, this attainment of equilibrium considered apart from the setting process at first proceeds rapidly, but the rate of increase of strength grows smaller, tending to a minimum.

A. Erskine Smith has shown (90) that there has been no permanent retrogression in the strength of cement in the case of specimens kept under observation for 21 years. Of course, this relates to laboratory specimens protected from weathering, but shows one of the directions which this metamorphism may take.

Hardening Process

The hardening of cement has been ascribed variously (48)

1. To the fineness of grinding,
2. To the increasing stability of calcium compounds due to combination of part of the silicic acid as the silicates grow less basic,
3. To the action of free lime upon calcium compounds,

4. To the decomposition of basic products present in the freshly set cement,

5. To equilibrium of calcium hydroxide with the siliceous constituents, and

6. To the hydration of the double silicates and anhydrides of lime and alumina.

The two theories that have at present the greatest claim upon consideration are that the strength of set cement is due to the progressive crystallization of calcium hydroxide (80), and, in some respects diametrically opposed, that this strength is due to the formation of a dense complex colloid, soft at first but gradually adsorbing calcium hydroxide and thus becoming harder and harder (64, 65).

According to the latter theory, cement consists of a mixture of fused compounds of silicic, aluminic and ferric acids with lime, together with an excess of lime, partly dissolved and partly enclosed. Upon the addition of water to this system it is decomposed, and the water becomes a supersaturated solution of salts, which react between themselves. The compounds resulting from these reactions crystallize about the cement grains in needle-shaped crystals. So far, the process is analogous to the setting of plaster of Paris (45), and silica takes no part in these preliminary reactions.

A hydrogel begins to form about each grain, in which the crystals become embedded. This hydrogel consists essentially of calcium hydrosilicate, and to a minor degree of calcium hydroaluminate and calcium hydroferrite. At first it is soft and plastic, but gradually becomes dense and rigid by the adsorption of calcium hydroxide. The strength of cement is mainly due to this process of coagulation.

The calcium hydroxide may of course crystallize and lend additional strength; but its crystallization is rather more likely to burst the hardened cell walls about each grain of cement, and thus admit liquids later in the process which may be fatal to the integrity of the structure, either by undesirable chemical reactions, or simply by dissolving away the lime, with the formation of soft hydrates of silica, alumina and iron oxide, instead of the desired hardened colloid (64, 65).

Much corroborative evidence has been offered by supporters of this view, and similarly by the exponents of the crystallization theory in defense of that. The question is still at issue, and the main difficulty is the microscopic recognition of the constituents of set cement (34, 78). Unquestionably, colloidal materials result from the action of water on silicates of this type, when the particles have been ground to the fineness of Portland cement (23, 21, 95). This has been directly observed in the case of cement and reproduced with synthetic mixtures. What binding power colloidal material may develop is strikingly seen in the case of conglomerates and sandstones in which hydrous silicic acid, aluminic hydroxide or ferric hydroxide has been the cementing material, so that the theory is attended by a high degree of probability.

On the other hand, it is also quite conceivable that the interlocking of crystalline masses between the grains of cement may account in some measure for the strength. There is definite evidence that calcium hydroxide does crystallize, and its mineralogical and crystallographic constants have been determined (24).

The two views are not entirely irreconcilable, and it is possible and even probable that, mechanically, the strength of cement acquired by hardening is due to both processes. Whatever be the chemical reactions in detail by which these elements of the structure are produced, the main condition for their occurrence is the presence of water.

This paper is devoted to an enumeration of the factors which influence the metamorphism caused by water in Portland cement, and the variations in the physical properties of the resulting rock, brought about by varying these factors.

Influence of Water upon Metamorphism

The action of water upon Portland cement is a resultant of

1. The temperature of the water
    - A. At first added
    - B. That may subsequently come into contact with the system
2. The quantity of water
    - A. At first added [4]
        - a. Size of cement particles
        - b. Mechanical agitation when water is added
        - c. Total water added
    - B. That may subsequently come into contact with the system
3. The quality of water
    - A. At first added
        - a. Having material in solution
    - B. That may subsequently come into contact with the system
        - a. Having material in solution
        - b. Having material in suspension

---

[4] Owing to the peculiar autoprotective reaction of cement against the action of water, before alluded to, the quantity of water coming into contact with cement is a function of the size of the particles and of mechanical stripping of protective films, as well as of the ratio of cement to water.

The final effects of geological processes do not differ in the main, whether these operate upon natural substances or upon the products of human industry. The agent whose activity is responsible for the majority of terrestrial changes, namely water, is also the main factor in the metamorphism of the artificial rock, cement. By intelligent control of the action of water upon this rock, the desired results are obtained, and its value as a material of construction is inestimable. Lacking this insight, the action of water may result in catastrophe, or at least loss of time, money or efficiency. Geology, then, through hydrology (59), is enabled to give substantial aid to the engineer.

TEMPERATURE OF THE WATER AT FIRST ADDED

In construction, the water at first added to cement, known as the gaging or mixing water, is subject to the entire range of variation of atmospheric temperature. The lower limit is far below the freezing temperature of water and of course, in this phase, water is useless for the purpose.

Within the possible range of temperature under working conditions, it has been established that as the temperature of the gaging water used is higher, the set becomes more rapid. Considering the setting due to the deposition of a network of crystals from the supersaturated mixing water, the beginning of this deposition would be sooner attained, if the water reached its condition of supersaturation more quickly; and this condition would be brought about by a higher original temperature, provided, of course, that the solutes increased in solubility with the temperature. With a higher temperature, the volume of the water would be greater and the viscosity less, and consequently its range of activity would be increased; that is, it would be enabled to reach a larger number of cement particles and thereby more quickly arrive at its saturation point, and the deposition of the crystalline network hastened in consequence. If the temperature of the mixing water be above about 37° C., the setting, instead of being hastened, begins to be delayed. If the deposition of this network were a simple case of precipitation from a hot solution, it would be logical to state that the solubility of the compounds concerned was so high at this temperature that they were not deposited from solution. The problem, however, seems chemical rather than physical, and it is more probable that this effect is due to hydrolysis.

Hydrolysis increases with the temperature. In the case of the weak salts that must exist in the system we have under consideration, the ultimate products of hydrolysis are the gelatinous materials—silica, in the hydrated form, aluminic hydroxide and ferric hydroxide. The adsorptive and coagulative properties of these materials unquestionably do not compare with the coagulative powers of the complex colloid which Michaelis postulates (64, 65). If, therefore, the hydration of cement does not proceed in a properly regulated manner, it is conceivable that it may become a hydrolysis, with deleterious effects.

If the mixed cement is allowed to freeze, the setting will not take place, but on thawing out the mass, setting is resumed. Obviously the transition of the water to the solid phase hinders solution and diffusion, and upon resuming the liquid form, water promotes these processes as before. A slow setting has, however, been observed in frozen mixes (94), and it is quite possible that the phenomenon of regelation may account for this.

Smoke gases have been found to have a disintegrating effect upon cement setting at a temperature lower than 7° C.; this is attributed to the formation at these temperatures of a hydrated calcium carbonate, having the formula $CaCO_3,5H_2O$ by the action of the carbon dioxide of the smoke gases upon the lime of the cement. At slightly higher temperatures this hydrate is transformed to pulverulent calcium carbonate, with consequent disintegration of the structure of which it forms a part (107).

The effects of moderate variations in the temperature of the mixing water upon ultimate strength are practically of no great moment; even mixes that have been frozen and afterwards allowed to resume their set are not materially affected in their ultimate strength, if the set has not proceeded too far at the time of freezing (11). More than one repetition of the freezing process upon the same mix, however, will be quite destructive to the final hardening.

If the hardening be considered a process of crystallization, repeated freezing may be assumed to destroy the strength by the formation, through rapid temperature changes, of relatively small and non-adhesive crystals of the calcium hydroxide during the critical foundation period of growth of the crystalline structure, so impeding and misdirecting consequent interlocking that a weak structure results.

If, on the other hand, the colloidal theory is adhered to, it is only necessary to point out that the colloidal cell walls about the cement grains may be ruptured by the expansion of the contained water in freezing. This would result in discontinuity of the internal structure, and if sufficiently widespread, as would be the case in repeated freezings, would alone account for weakness.

Studies have been made of the ultimate resistance obtained from frozen mortars by varying the amount of gaging water, with the view of establishing whether "wet" or "dry" mixes best resist the disruptive effects of frost during setting. The results reported are discordant. An excess of water has been found by one investigator to enhance the effects of frost (85), while by another it has been found to diminish them (11). Theoretically, the disruptive effects of freezing should be enhanced by the presence in the mass of larger quantities of gaging water. On the other hand, it can be assumed from the colloidal standpoint that an increase in the amount of water present will result in the formation of a greater quantity of colloids and a greater elasticity of the resulting mass, together with a smaller total breakage of cell-wall material.

TEMPERATURE OF THE WATER THAT MAY SUBSEQUENTLY COME INTO CONTACT WITH THE SYSTEM

The action of hot and boiling water upon set cement is strongly marked in the case of cement which contains free lime, producing after a few hours, swelling, distortion and cracking and even total disintegration. A normal cement so treated, however, preserves its original form and volume after short periods of exposure to the boiling temperature.

The viscosity of water at high temperatures is greatly diminished, and the liquid is thereby enabled to penetrate more rapidly the capillary and subcapillary voids, thus reaching more quickly a larger internal area. If, as in the case of an unsound cement, free lime is thereby reached, this is slaked much sooner than it would be under normal conditions, and moreover with great violence, owing to the higher temperature of the water, producing internal disruption, and perhaps thus opening up further avenues to the penetration of water, with a repetition of the slaking process.

The boiling test here described is a very important one in the testing of cement for construction, but it is perhaps less reliable in the case of unsoundness from the presence of excess of magnesia.

In cements stored in waters of relatively high temperature, it is probable that the processes of solution act more rapidly, from the two reasons mentioned above; but evidence is lacking to show that any significant decrease in ultimate strength is thereby occasioned.

Data as to the storing of cement in waters of low temperature, yet not subjected to the action of frost, are not available in the literature, but they would be interesting.

In the case of exposure to the action of frost, the process is quite similar to that which goes on in the disintegration of natural rocks and depends, in like manner, upon the initial mechanical resistance of the mass, upon the total volume of the voids and upon the ratio of capillary to subcapillary voids. The disruptive effect is, of course, due to the expansion of the water during freezing. Consequently there is a possibility that during the earlier stages of the history of the mass this effect may be to a great extent neutralized by the presence of soft colloidal material (45), because of its lack of rigidity.

Voids are undoubtedly present even in neat cement mixes, and they are more common in mortars and in concretes; when, therefore, these have attained a sufficient hardness, they are in all respects similar to a natural rock and subject to the same katamorphic processes. The effect of frost increases in intensity as the mass ages and loses elasticity.

As water permeates the cement, even after hardening has progressed to a considerable extent, it becomes charged with various electrolytes, and its freezing point is consequently lowered. To some extent this immunizes the mass from frost action. On the other hand, as we have seen before, cryohydric compounds may be formed at these low temperatures, and the separation of these from solution is a factor in the opposite direction.

QUANTITY OF WATER AT FIRST ADDED

Size of cement particles.—The finest particles in cement, provided that they are chemically identical with the remainder, are the most active cementitiously, because of the ease of reaction and of the greater probability of this action being uniform throughout the mass of each particle. This is recognized under the microscope by the ultimate disappearance of these particles as individuals upon the addition of water. Owing to the relative insolubility of the constituents of cement, both before and after metamorphism, each particle becomes covered to a certain depth with the reaction products, which in this case take the shape of gelatinous films (2) in such manner as to offer hindrance to the further action of water.

The particles whose diameter is smaller than or equal to the thickness of this zone evidently are the most efficient chemically. The larger particles are less so, as the passage of water through the enveloping film is a slow matter, and some particles may be so large as to remain internally unchanged. It is probably this fact that gives a hydraulic quality to previously set cement that has been reground and retempered with water; in fact, this process may be repeated a number of times with the same sample of cement.

Not all of each particle, therefore, can take part in the setting and hardening, and sometimes this proportion of inert material is considerable (86). The coarser particles are comparatively inert and might be replaced by grains of foreign material of the same size without materially influencing the ultimate strength of the resulting mass. This has been demonstrated experimentally (17). It does not follow, however, that a cement consisting entirely of uniformly very fine particles would be a desideratum, since such a cement would not pack as well as one containing a greater variety of sizes, and the increase in chemical activity would be markedly overbalanced by the imperfection of structure of the mass. Considering each particle to be spherical, and of equal size with every other, when packed in the most compact manner possible the pore space would be nearly 26 per cent (89). The points of contact of the adjacent spheres, notwithstanding the tendency of the gelatinous envelope to spread, would be relatively few. If, however, this pore space were filled with finer material, the structure would develop more strength. The function of part of the cement is to remain passive and to add to the strength of the structure merely by its action of void-filling. Extremely fine grinding has been found to decrease the ultimate strength, if the cement is used neat, but to give greater strength, if the cement is used in a sand mortar (62).

As might be expected from the above considerations, the fineness of grinding has an accelerating effect upon setting. Cement ground in a tube mill until only 1 per cent remained on a sieve having 5000 meshes per sq. cm., was so quick setting that it could not be restrained even by the addition of 10 per cent of gypsum (47). When cement is relatively coarsely ground, the ultimate strength is not so quickly attained, but its acquisition is regular and uniform.

Laitance.—In concrete construction under water, especially salt water, there gathers about the freshly deposited concrete a milky white cloud of suspended matter, technically known as laitance. This material is also formed when concrete is mixed very wet, though not deposited under water.

An analysis of laitance by the writer, made for the Board of Water Supply, practically coincides with an analysis made by Richardson (97) and leads to the same conclusion as that reached by him; namely, that laitance represents an actual loss of cement and consists of the finest particles of cement which have been washed out of the concrete. The additional conclusion is justified that this portion of the cement, by reason of the small size of its units, has been so acted upon by an excess of water that it has undergone complete hydrolytic decomposition, before the colloidal enveloping film had adsorbed sufficient electrolytes to completely coagulate it and so render it largely impermeable. This is substantiated by the fact that laitance possesses neither setting nor hardening qualities.

Hydrolysis theory.—The formation of such a protective film upon the surface of a coarse particle will so regulate the access of water to its interior that the contents will be slowly and normally hydrated. If the entire mass of the particle were at once accessible to an excess of water, the weakly acid and basic compounds at first formed would soon be hydrolysed and shorn of their binding power, and instead of the normal complex colloids described by Michaelis (64, 65), capable of adsorbing electrolytes and so coagulating into a dense rigid mass, simpler colloids such as hydrous silicic acid and aluminic hydroxide would form, which have not these powers to so high a degree.

Finally, the rate of setting and hardening of a cement may be considered a function of the proportion of fine particles present. Mortars set and harden more slowly than neat cement, and concretes more slowly than either. This is simply a development of the fact that coarsely ground cement sets and hardens more slowly than that which is finely ground. It may be considered, from another viewpoint, that the inactive material interferes with the liberation of heat from the system, and that chemical reaction is consequently delayed in proportion to the amount of inert material present.

Mechanical agitation when water is added.—If cement in the state of a plastic mass be worked and kneaded, the ultimate strength will benefit thereby, up to a maximum time of working. It is legitimate, *a priori*, to surmise that the setting is hastened, within limits, although no record of this is found.

After the maximum time referred to, which in experiments made at the Board of Water Supply laboratory has been found to correspond roughly with the time of initial set, continued working will cause a falling off in the strength. Up to this time, mechanical agitation with the proper amount of gaging water will cause an increase in the ultimate strength.

The formation of the crystalline network, which constitutes the setting of cement, and which is responsible for the primary strength by holding the plastic mass rigid and in place, while the more important elements of hardening make their appearance, is unquestionably facilitated by agitation. Stirring is a means of hastening chemical reactions by bringing the agents into more intimate contact. The compounds that go to make up this network, being sooner brought into solution, perform their function more quickly, and the crystals begin to form. Instead, however, of forming a continuous rigid network, the crystals will be smaller and less cohesive than if undisturbed in their growth, and the set can be delayed and even prevented by continuing the agitation long enough.

The ultimate resistance of cement which has been thus treated is decreased as well. The formation of the coagulated colloid, or of the interlocking crystal units, whichever may be the cause of hardening, is rendered imperfect and discontinuous, and the structure reflects the weakness of its component units.

It may moreover be supposed that more cement has been brought within the range of hydrolysis by this agitation, and so converted into laitance, even the larger particles being stripped of their protecting films by the attrition. Tests made at the Watertown Arsenal (36) showed that after one hour's working, cement had gained 4 per cent over the normal strength, but that after 10 hours' working, it had lost 24 per cent from the normal, in 20 hours 38 per cent, in 50 hours 56 per cent and in 100 hours 69 per cent.

Total quantity of water at first added.—Under certain conditions, the entire range of particles of a cement might be destructively hydrolysed, resulting in what is termed "drowned" cement. The effect of an increase in the quantity of mixing water is known to result in a diminution of strength, and, bearing in mind what has been previously said regarding hydrolysis, the reason is clear. If, before the cementing of contiguous particles, an excessive amount of water is admitted to contact with the cement, colloidal material will form in increased amount. It has been shown that an increased amount of mixing water results in an increased volume of the paste produced (39). This indicates that a larger amount of the products of hydrolysis is formed.

Owing to difference in composition between these hydrogels and those formed under normal conditions, they are incapable, as has been before observed, of adsorbing electrolytes in such degree as to attain to the density and rigidity of the latter. Admitting, on the other hand, that colloids so formed do not differ in composition from those formed in the normal hardening of cement, there still remains the abnormality of the structure formed in this way. Being discontinuous, it would not offer the same total resistance, in the form of connected films, to the passage of water. Moreover, in the presence of an excess of water the working ratio of electrolytes to colloids would be less because of the greater dilution in proportion to the volume of colloid.

QUANTITY OF WATER THAT MAY SUBSEQUENTLY COME INTO CONTACT WITH THE SYSTEM

The effect of water upon cement after it has completely set rapidly diminishes to a negligible quantity at ordinary temperatures, if the water is reasonably free from dissolved or suspended impurities. There is a leaching out of calcium hydroxide from the mass of the cement; but this diminishes as the mass grows more and more impermeable, by the coagulation of the colloidal cell walls and by the carbonation or other precipitation of lime salts in the pores.

This deposition of lime salts in the pores is evidently the cause of higher strength in specimens which are allowed to dry out a few hours before testing. It is analogous to the higher strength developed by seasoned stone than by freshly quarried stone, occasioned by the evaporation of the "quarry sap." In addition, the carbon dioxide conveyed to the material in a gaseous form is absorbed by the lime and may be considered a positive factor towards strength, while that conveyed in solution (where the cement is under water) is a negative factor, in that it accelerates the solvent effect of the water coming into contact with the cement. On the other hand, cement specimens which are entirely air-hardened are unquestionably weaker, by reason of the absence through evaporation of the requisite amount of water for proper hydration.

When the action of water upon set cement is intermittent, the solvent effect manifests itself by unsightly incrustations and discolorations (3), caused by dissolved material brought to the surface through capillary action and there deposited by evaporation. When the mass is permanently under water, these salts are merely washed away. The danger from these incrustations, although slight, is the disintegrating effect produced by their increase in volume, through crystallization or efflorescence, and the consequent disruption of the denser surface skin, rendering easier the action of frost upon the entire mass.

This surface skin is improved by troweling the cement while in a plastic state, and consists of a closely packed layer of fine particles, which offers high resistance to permeation by water and comparative immunity from the solvent action favored by a rough, porous or fractured surface.

If the mass be placed in water before setting, it is more liable to hydrolysis, as evidenced by the copious formation of laitance; and if greatly exposed, as by agitation under water, it may fail to develop the greater portion of its normal ultimate strength. To prevent this, care is taken, in laying concrete under water, so to convey it that it offers the least possible surface to water action during its descent; and to this end it is either lowered in cloth bags, or filled in through a chute, so as to escape all avoidable exposure to hydrolysis.

If the water which comes in contact with a cement structure be under considerable pressure, so that its tendency is to percolate through the mass, the solvent effects will of course be magnified, proportionally to the porosity of the mix; and experiments made by the Board of Water Supply have shown that concrete subjected to such percolation has been shorn of the major portion of its ultimate strength. In this case, the solvent effect of the water is only part of the influence at work, purely mechanical factors entering largely into the destructive process, as will be shown later.

Stalactitic growths of lime salts form as the result of water percolating through concrete. Micro-organisms of the algal type frequently lodge in the pores of concrete and by their growth may act as a protective influence against the permeation of water. The effect of their products of metabolism and decay upon the concrete structure has not been studied.

Numerous waterproofing materials and processes have been devised (40, 73). They may be grouped conveniently under three heads.

Surface treatments.—The application to the surface of concrete of a coating similar to a paint has the disadvantage that concrete is not a thoroughly dry material. Where the vehicle is a liquid immiscible with water, the paint will not therefore come into contact with the concrete proper. If the vehicle is miscible with water, unless insoluble products are at once formed by reaction with the constituents of cement, the active agent is quickly leached out.

Membranes.—These are layers of waterproof tissue interposed between two layers of the concrete. There is strong probability that these never actually form a bond with the concrete, and thus they necessarily introduce an element of weakness and heterogeneity.

Mass treatments.—The active material is incorporated with the concrete at the time of mixing, either by dissolving or suspending in the gaging water, or by intimately mixing with the cement or sand. These treatments are many and differ widely in the agents employed. Substances of a waxy or fatty nature, triturated to a great fineness, are the most generally offered, but the incorporation of these in a mass of concrete is generally followed by weakness of the structure. The general problem of cement waterproofing has been conceded to be simply a question of void-filling, yet this must be accomplished without the addition of inert material that will weaken the resulting structure.

The addition of more colloidal material has been suggested. This is ingeniously effected in a recent process by the use of hydrolysed cement, obtained by treating cement with an excess of water (99). The paste so obtained is added to the cement during mixing.

The still unclarified state of our knowledge of the chemistry of the setting and hardening of cement is the great handicap which has thus far prevented the devising of a satisfactory waterproofing agent. A large number of the waterproofing preparations on the market are therefore purely empirical, and not applicable to the practical waterproofing of large masses of constantly wet concrete. In the interests of efficiency, it is probably more economical to expend money destined for waterproofing in the purchase of additional cement to be used in making a richer concrete.

QUALITY OF WATER AT FIRST ADDED

Having material in solution.—On adding water to cement, heat is evolved, the temperature of the mix rising in some cases to above the boiling point of water. It is the custom to look with suspicion upon cements in which an excessive rise of temperature is obtained, as being liable to develop unsoundness. The abnormal rise is attributed in some instances to the presence of free lime, in others to an insufficient proportion of lime. The volume changes caused by a rise in temperature have been given as the reason of the difficulty encountered in joining fresh cement surfaces to old, causing weakness at the plane of juncture, the contraction of the mass on cooling breaking the joint before it has developed sufficient strength to resist the strain.

To prevent this, it has been suggested to coat the surface to which fresh cement is to be applied with a retempered mortar; that is, with a cement which has been treated with water after partial setting. This provides an intermediate course of material in which the temperature changes are not so rapid, and upon this course the fresh cement mixture is applied (35).

Upon the same principle may be explained the use, for a fresh course of cement which is to be joined to some which has previously set, of mixing water in which a quantity of cement has been stirred, thus retarding the chemical reaction and consequent temperature changes. In both cases, the active water is already charged with the soluble portion of cement, its solvent power for the same material is thereby diminished and the chemical action moderated, so that heat is more gradually evolved and violent expansions and contractions avoided.

The influence of dissolved electrolytes in mixing water has received much careful study. Through the addition of a small percentage of some soluble salt to the mixing water, many have tried to influence the properties of the completed structure and to produce a mass that would develop greater strength or a higher degree of imperviousness. Unfortunately, the panacea has not as yet been discovered that is suitable for practical application.

The addition, similarly, of a soluble powder incorporated in the mass of the cement comes under the same category. In this connection, our attention is drawn to the effect of the usual addition of ground gypsum or of plaster of Paris to the ground clinker, for the purpose of retarding the set. There are other salts whose retarding influence on the set of ground clinker is comparable and probably superior to that of gypsum, but their use is not so practical, consequently, it has been adopted as the restrainer for general use.

It has been shown by Rohland (83) that the salts which respectively accelerate and retard the setting of cement are the same as those which accelerate and retard the hydration of quicklime. From this it is concluded that their influence is "catalytic."

A detailed explanation of the mechanism of the action of gypsum has been put forth (79), holding that the presence of calcium ions in the mixing water, resulting from the solution of gypsum therein, decreases the solution of other calcium ions, thus retarding the solution of lime and the hydrolysis of the aluminates, which in turn retards the set.

It seems probable, upon this basis, that the presence of certain electrolytes in the mixing water acts upon the set by influencing the solubility of calcium sulphate therein, and consequently increasing or diminishing the number of calcium ions present in the mixing water as a result of the solution of calcium sulphate.

For example, sea water has been found to retard the set of cement (83). Gypsum, although a relatively insoluble salt, may be regarded as fairly soluble in moderately strong solutions of sodium chloride or of other salts having no common ion (14). In the presence of sodium chloride, then, the calcium ion concentration in the mixing water is raised, and the solution of the calcium aluminates diminished, with the effect of retarding the set. Sulphates have been found, when dissolved in the mixing water, to have the property of retarding the set, with the exception of aluminum sulphate and calcium sulphate when in low concentration. In view of the latter fact, it is evident that the above explanation is perhaps only a partial one.

A large number of other electrolytes and miscellaneous compounds have been investigated and the results are recorded (83).

The effect of soluble constituents in the sand used for making concrete is by no means negligible (4) and may offer an explanation for many instances of puzzling behavior of the mixture.

Sea water has been and is, in many instances, still used for mixing concrete, and to the best of our knowledge, no cases of failure can be attributed to this cause alone. Apart from the influence upon setting, the presence of dissolved electrolytes in the mixing water seems to increase the strength of cement in the early periods, as far as reported results have shown (4). This may perhaps be due to an increase of coagulation of the colloidal constituents, by reason of the presence of salts of greater ionization than are generally present. On the basis of the crystallization theory, this phenomenon is rather difficult to interpret.

QUALITY OF WATER THAT MAY SUBSEQUENTLY COME INTO CONTACT WITH THE SYSTEM

Having material in solution.—A large number of failures in concrete structures have been attributed to the disintegrating action thereon of water impregnated with various salts. Inasmuch as all ground water is charged to some degree with salts which it has accumulated in its passage through the soil and rocks, this problem is worthy of the most careful attention. For our purpose, such mineral-laden waters may be divided into

1. Sea water
2. Alkali water (from western alkali soils)
3. Deep rock waters.

The mineral constituents are common in all these cases, and vary only in the prominence of one or more of them. Thus in sea water the chlorides of sodium and magnesium, in alkali water the alkaline carbonates, and in deep rock water the chlorides of calcium and magnesium and the sulphate of magnesium are the distinctive constituents. Whether the effect of these electrolytes is cumulative, so that the continued action of solutions of low concentrations will work harm, or if not, what are the limiting concentrations to assure safety to the structure, has not been worked out. Obviously, it is not a laboratory problem, since the factors which obtain in nature are impossible to duplicate on a small scale. The solution lies in careful inquiry into the mechanism of the action and in observation of the instances of failure in construction work, with a study of its causes.

Sea water.—The effects of sea water upon set cement have been summarized in the statement by Feret, "No cement has yet been found which presents absolute security against the decomposing action of sea water" (97). Le Chatelier, after a series of experiments extending over ten years, confirms this conclusion (53). Poulsen concludes, however, that the chemical action of salt water is not alone sufficient to cause Portland cement mortars to deteriorate (76).

The diversity of results reported in the observation of the action of sea water upon cement indicates that there are varying factors at work that so far have not been clearly recognized. Whether the precise nature of the action is physical or chemical is not quite settled. There are not lacking investigators who assert that the destructive action is mostly physical and is due, among other causes, to intermittent submergence and consequent deposition, by evaporation of crystals in the pores of the structure, which, either by their pressure of formation or by expansion during efflorescence, have a disruptive effect similar to that of frost (98).

There are those who hold that the action is entirely physical, and is due to this factor and the effects of frost (91, 102), although probably the latter is seldom the case in sea water, owing to its low freezing point (50). The effect of direct sunshine has been found deleterious when alternating with that of tidal action (20). Undoubtedly, all of these factors contribute to the total effect, and there is as well a marked chemical action.

The chemical effects of sea water upon cement are capable of various interpretations. They are summarized as the formation of complexes by the action of the dissolved sulphates and chlorides in the water upon the calcium silicates and aluminates of the cement (74). It has been stated that sodium chloride solutions have the power of dissolving calcium silicate with the formation of an unknown salt (58, 70), and also that the sodium chloride enters into combination in the mass, the chlorine ion entering into the combination calcium chloro-aluminate, and the sodium ion combining with lime, silica and alumina, to form compounds of the nature of the zeolites.

Working with strong solutions of the individual salts of sea water, it has been found that the chief harmful constituent is magnesium sulphate, and it has been suggested that this salt reacts with the lime of the cement to form calcium sulphate and magnesium hydroxide. The calcium sulphate further reacts with calcium aluminate to form a calcium sulpho-aluminate, which by swelling causes the disruption of the mass. The magnesium hydroxide formed has been regarded as a restraining agent, by virtue of its filling up the pores of the cement and preventing further ingress of sea water (70). Again, the disruption has been directly attributed to the increase of volume caused by the formation of this magnesium hydroxide (46). It has been calculated that, apart from the formation of hypothetical sulpho-aluminates, a molecularly equivalent amount of calcium sulphate replacing the calcium hydroxide of the cement occupies 2.08 times as much space and is, therefore, the cause of the disintegration (13).

Alkali and deep rock waters.—Burke and Pinckney (13) have formulated a working theory of the action of the various salts common to all natural waters. They attribute the disruptive action to more rapid removal of the calcium hydroxide, and in some cases to its replacement by material occupying greater volume, as before shown, and consequent disintegration of the structure.

That some such reactions occur is indubitable, and that the mechanical factors are a large influence in the disintegration is equally certain. An additional cause which may be of great importance has hitherto been neglected. The electrolytes in these natural waters may act as accelerators of hydrolysis, and, in effect, cement which is in contact with sea water is subject to the same action as that of an excess of water from any cause. By the presence of these electrolytes the hydrolysis of a larger proportion of the cement is effected; and the results are increase in the volume of the hydrolysed portion, and production of a larger proportion of inert colloids. It has been found that a larger amount of cement can be converted into colloidal matter by the presence of an electrolyte in the water with which it is treated (99), and also that the speed of hydration of cement is affected by the presence and proportion of electrolytes present (84). The fact that a larger amount of laitance appears to be formed in sea-water construction also seems to bear out this theory.

Besides the reactions mentioned, set cement is subject to the replacement of silicic acid by carbonic acid, as are the natural rocks. Especially is this true in cases where the cement comes into contact with marsh and peaty waters and waters containing ferrous carbonate, which by transformation to the hydroxide liberates carbon dioxide (24), which has been found to act, not only upon the calcium hydroxide but also upon the silicates and aluminates (28).

The presence of free acids in water which acts upon the cement is quite destructive, in proportion to the concentration of the acid and to its strength or weakness as an acid. It is quite probable, however, that the liberation of colloidal silica by the action of acids would serve to a great extent as a protective influence against their further action.

Sewage gases are generally effective by reason of the hydrogen sulphide which they contain. This gas is readily oxidized to sulphuric acid, and then its action is the production of soluble calcium and aluminum sulphates, which are subsequently leached out from the mass. This action has been found greatest at the surface of the liquid (106). Hydrogen sulphide may also act by converting the iron of the cement into sulphide, and this becomes oxidized into ferrous sulphate and is leached out, or by its expansion causes disruption (28).

The action of many other inorganic and organic solutions has been observed, but they do not come within the scope of this paper, since they are not met with in natural processes.

In general, the consideration is worthy of attention whether concrete structures which are under stress are not more liable to chemical disintegration than those which are in repose, or whether a single structure is not more liable to this action in its strained parts than in those not so affected. We have data to show that strained iron is more liable to corrosion than unstrained, and it has been asserted that strained minerals are more acted upon by underground solutions (104).

A number of protective measures against the action of saline waters upon concrete have been suggested and tried, but none has been so strikingly effective as to achieve universal recognition. The simplest remedy suggested is to make the concrete for such uses denser and more impervious by the employment of a greater proportion of cement, yet this may not always be practicable. When concrete is exposed to the gases resulting from the decomposition of sewage, it is suggested that even such a proceeding may be of no avail (29).

Previous air-hardening of the concrete before laying under sea water is acquiring more widespread use and is highly recommended (87). The cause of its protective action is attributed to the carbonation of the calcium hydroxide (48).

Variations in the fineness of grinding and in the chemical composition of the cement used in concrete for sea-water construction have been proposed. The French specifications for sea-water cements call for a finer grinding than that which is required for ordinary construction. Much has been claimed regarding the resistance to disintegration offered by the so-called "iron ore" cement, which contains a minimum of alumina, this being almost entirely replaced by iron.

Having material in suspension.—The peculiar nature of the series of compounds forming and formed from cement, in that they are all of relatively low solubility, tends, as has been before observed, to retard the reactions which may occur. Mechanical agitation, by promoting diffusion and by transporting the reacting materials to their possible spheres of action, will accelerate these reactions. The motion of water, *per se,* can and does produce this effect, and when the water is armed with suspended material, its activity in this direction is greatly enhanced.

Where water has immediate access only to the outer surface of a mass of set cement and its pressure is low, the effect is a slow corrasion of the dense surface skin and ultimate removal thereof, rendering the interior gradually more accessible. Ordinarily, this process is a slow one, although under certain conditions, as in coast protection works where the velocity of the water is high and the suspended material coarse and plentiful, the destructive effects are more to be reckoned with.

The effects from less spectacular processes are quite surprising. Where the pressure of the water is such that there is a marked motion of the water within the pores of the concrete, the erosion is internal and far more insidious. In this case, the suspended material is part of the structure itself. Small particles of cement or, in the case of mortar, grains of sand which become detached from the parent mass are whirled around by the water stream and shortly enlarge the cavity in which they are rotating, until it merges with some adjacent cavity. Under favorable conditions this process may continue until the interior of the structure is greatly weakened.

A factor which to some extent neutralizes the flow of water through concrete is the choking of the pores by sediment, coming from the water itself or furnished by the action of the water upon the concrete. If the flow is oscillatory, as in concrete exposed to the range of the tides, this protective effect will of course not be so marked (54).

Diatoms and other microscopic marine organisms with siliceous or calcareous tests undoubtedly play an extensive part in the preliminary stages of this internal mechanical action, by choking the capillary spaces. At the same time, undoubtedly, the organic debris thus introduced may by its decomposition give rise to substances, carbon dioxide and hydrogen sulphide, for example, which have an accelerating action upon the processes of solution, and the silting effect may thus be neutralized or even overbalanced.

PART II

Experimental Investigation

In Part I, the ways in which water may influence the metamorphism of Portland cement were discussed qualitatively, and their possible effects upon the permanence of the structure of which cement forms the basis were pointed out. This question has now assumed economic and vital importance.

In the following pages experimental data are offered, in elaboration of the outline laid down in the first portion of the paper. Points in the scheme which have been established beyond doubt by previous investigators are here omitted, and only such results are inserted as have been deemed necessary as additional evidence. The last division of the outline, treating of the action of suspended material in water in effecting the erosion of concrete, has not been experimented upon, not having come within the scope of the writer's activities, and therefore is omitted.

Other divisions have already been so thoroughly covered by previous investigators that very little remains to be said about them. Emphasis has therefore been laid in this paper upon the little known fields.

The problems which confront the user of concrete are of a high order of complexity. The generalizations of chemistry are not yet sufficiently developed to apply rigidly to systems of so many variables, and experimental work on a laboratory scale often fails almost entirely to reproduce the conditions of practice. The best guide to the truth, then, is the pragmatic sanction of experience—the investigator in this field can but point out probable directions for future experimentation. The theories which underlie past success are a safe guide, nevertheless, to future construction, and the systematization thereof is a legitimate field of usefulness.

While, strictly speaking, any aggregation of chemical compounds might be considered a rock, whether natural or artificial, a majority of the cases conceivable under such a classification would not present important petrological problems in the study of their metamorphism. Such a problem as the action of water upon a mixture of sodium chloride and calcium sulphate can be partly solved *in vitro,* even though the action of sea water upon gypsum deposits is an interesting petrological investigation.

The important components of Portland cement are everywhere about us in nature, and the reactions by which it is made artificially have been taking place for many geological ages without the intervention of man. Silica, alumina and lime are among the most important constituents of the earth's crust; they are subjected in places to the same conditions that exist in the kiln, and are afterwards acted upon by water, under some of the same conditions under which man builds massive structures.

The complex question of the history of rock magmas is not one to be solved by any one group of scientists, but by patient and concerted efforts of the chemist, the physicist and, above all, the petrologist. So the problem of the constitution of Portland cement may be as yet somewhat indeterminate; but an examination of the more general effects of metamorphism may reveal some identity with conditions in natural rocks already studied and may direct us to the correct methods for investigation of the constitution of cement (67).

Other important problems in the field of cement and concrete are referred to in the following pages, and belong in great measure to the field of petrology. Not the least important of these is the suitability of various types of rocks for use as aggregates in concrete, and this work is claiming more widespread attention daily (19, 44, 111).

TEMPERATURE OF THE WATER AT FIRST ADDED

Two standard cements were gaged with the requisite quantity of mixing water for each at different temperatures. The effect upon the time of initial and final set was noted, as follows:

Table 1

Effect of Temperature of Gaging Water on Time of Initial and Final Set

Per cent by weight of mixing water		Temperature of mixing water	Initial set, hours		Final set, hours	
A	B	A and B	A	B	A	B
22	21	70° F.	4.25	4.50	6.75	7.50
22	21	100° F.	1.50	4.00	4.00	7.00
22	21	150° F.	0.33	3.75	0.50	5.75
22	21	212° F.	1.00	2.75	2.75	6.00

The results seem to indicate that interference of hydrolytic decomposition with the setting appears between 150° F. and the boiling point of water. Below these limits, the effect of increase of temperature of the mixing water, as is well known, is to increase the speed of setting (31). The setting time at these temperatures is a resultant of two opposed processes,—the formation of the water crystalline network, and the destructive hydrolytic action of water upon the original constituents of the cement, resulting in a product which has no hydraulic qualities.

Where the second process overbalances the first is the point at which the speed of setting ceases to increase and begins to diminish.

This is true of course of the stage known technically as the final set (9). In the first few hours of setting, there is a period of relaxation, which McKenna has aptly termed reverse set, and which he has been able to detect with precision by means of an ingenious chronographic apparatus of his invention (60). The phenomenon has been observed by the writer and his associates in the laboratory of the Board of Water Supply, using the Vicat needle; but this apparatus does not lend itself to a scientific study of the finer differences in rigidity which occur during the setting period. McKenna's apparatus should throw a great deal of light upon the initial metamorphism of cement.

TEMPERATURE OF THE WATER THAT MAY SUBSEQUENTLY COME INTO CONTACT WITH THE SYSTEM

High pressure steam.—Wig (109) has recently presented an account of the excellent effects of high pressure steam when used in curing concrete. He found that by using concrete that had attained its initial set and exposing it to steam at 80 pounds pressure the six months' strength could be obtained in two days, a tremendous accelerating of the hardening process.

This state of affairs is not very satisfactorily explained, if the hardening of cement is supposed to be due to the progressive crystallization of calcium hydroxide, since it is somewhat at variance with our knowledge of the conditions of crystallization to assert that continuous exposure to a high temperature, presumably constant, should accelerate crystallization; particularly since in this case the amount of water present in the system remains the same. On the basis of the colloid theory, however, it is simply explained by supposing that adsorption of calcium hydroxide by the complex hydrogel is accelerated by higher temperatures.

Cold storage.—A series of tests, embracing neat cements and mortars, was made upon tensile test specimens exposed, after the age of 24 hours, to low temperatures under diverse conditions. The following conditions were observed:

1. Chilling the briquettes at 24 hours' age by filling the storage tank with water at the lowest winter temperature as it came from the tap. The water was then allowed to come slowly to normal winter temperature for the tank, about 60° F.
2. Chilling another set of specimens, otherwise normally treated, by filling the tank with cold water as before, 24 hours before breaking.
3. Storing another set in ice water for the entire period after removing from the damp closet at 24 hours' age.
4. Normal treatment.

Two brands of well-known cement of high quality were run in parallel. The mortars were of proportions 1:3, Ottawa sand being used. The results obtained are summarized below:

Table 2

Effect of Cold Storage on Strength

Cement	Mix	Temperature of storage water, deg. F.	Storage method	Strength, pounds per square inch		Per cent of loss		Number of specimens
				7 days	28 days	7 days	28 days	
X	Neat	60	Normal	735	739	0	0	10–12
		43	1	606	693	18	6	12–12
		42	2	654	735	11	0	12–12
		60	Normal	702	745	0	0	24–24
		34	3	638	665	9	11	24–23
X	1:3	60	Normal	300	361	0	0	11–12
		43	1	281	361	6	0	11–11
		42	2	283	371	6	+3	11–11
		60	Normal	313	408	0	0	24–24
		34	3	262	312	16	24	22–24
Y	Neat	60	Normal	628	843	0	0	12–12
		43	1	650	770	+3	9	12–12
		44	2	649	872	+3	+4	12–12
		60	Normal.	628	697	0	0	24–24
		34	3	530	622	16	11	22–24
Y	1:3	60	Normal	250	350	0	0	12–12
		43	1	253	370	+1	+6	12–11
		44	2	287	327	+15	+7	12–12
		60	Normal	228	317	0	0	22–24
		34	3	197	234	14	26	22–24

From these results, it is safe to conclude that, aside from the effects of frost, low temperatures are adverse to the development of the hardening process in cement, and that in general this effect is more pronounced in mortars than in neat cement.

The adsorption of calcium hydroxide by the complex hydrogel may proceed at a lower rate at lower temperatures; or if this is not so, the primary hydration, of which this hydrogel is the product, may proceed more slowly, and thus less of the hydrogel be produced,—either of which processes will detract from the hydraulic activities of the mass. It would seem from the experiments that the latter is the more satisfactory explanation, since the test specimens which were chilled at first and allowed to return to normal temperature show a tendency to return to normal strength at the longer periods, while the general tendency in the series kept constantly in cold water is to fall further off from the normal, indicating only a limited available amount of hydrogel to undergo the coagulating process.

The effect of sudden chilling at a period when a large proportion of the strength is already developed does not show any decided direction, both the positive and negative variations from the normal averaging the same. It may therefore be concluded that, for the temperatures studied, a chilling of this kind has no significant effect.

An explanation according to the crystallization theory of hardening would fail to fit the facts so satisfactorily. In the specimens that were chilled at first and allowed to return to normal temperature, there should be under this hypothesis a more significant decrease of strength, owing to the formation of small, non-cohesive crystals from the rapid temperature change. The return to normal conditions should not favor so nearly complete a recuperation as has been noted; unless a re-solution of the crystals and recrystallization were supposed, in which case it may be argued that such a process would require an abnormal solubility of small crystals when compared with large. In a normal specimen, re-solution and recrystallization are undoubtedly going on, strengthening the structure, and the large crystals are growing at the expense of the small. If small crystals preponderate at seven days' age, resulting in a weak mass, it is necessary to postulate a comparatively high solubility of the small crystals in order to arrive at a normal strength at 28 days. This, while by no means impossible, is not probable.

Turning to the specimens kept continuously in cold water, it would seem that, although the first chilling should show severe effects, as it did, there should not be such a falling off in the rate of hardening, if the crystallization be progressive. It is quite possible, however, that crystallization at this temperature is not favored, and that the total number of binding crystals of calcium hydroxide is therefore less than at normal temperatures.

QUANTITY OF WATER AT FIRST ADDED

Size of cement particles.—Other factors being equal, the amount of cement rendered inert by the action of water is proportional to the percentage of fine particles. This is an absolute condition and presupposes free access of water to every particle. Needless to say, in practice this condition is seldom realized, except approximately in laying concrete under water, or in the careless use of an excess of water in mixing, or in protracted mixing.

In the use of a very fine cement, then, if the proper proportion of water is added, the mixing time carefully regulated and proper precautions taken in depositing, the influence of texture upon the strength of the mass occasioned by the action of water is reduced to a small quantity, by virtue of the greater hydraulic activity of the fine particles, increasing the impermeability, as will be shown, and the confining therefore of the action of the excess water to a narrow zone. The bulk of the cement will be properly hydrated in spite of the fineness.

The investigation of the effect of the size of particles due to the action of water thereon alone is not feasible, because no satisfactory measure of laitance formation, except the strength of the mass, has been devised. The measure of the strength would be unsatisfactory, since the proportion of fine particles affects the strength in other ways than through the formation of laitance, as has been pointed out in a previous communication.

From a study of the hydraulic properties of reground cement, Spackmann and Lesley conclude (93) that only the very fine flour in cement, that portion not measured by the present tests using sieves, reacts when gaged with water and gives strength. It is difficult, of course, to draw a sharp dividing line between active and inactive material in cement, although it must be admitted that the greater part of the coarse material, even though it be of the same chemical composition as the fine, has little or no cementing value and serves mainly as a filler.

Suitable fractional separation of the portion of cement passing the 200 sieve, by air-elutriation or other method, should with careful study be a valuable guide to the most efficient mechanical composition. Experiments upon the first method of separation are recorded by Peterson (71), and a scientific method of fractional elutriation using an inactive liquid has been worked out by Thompson (100). Much should be gained by the application and development of these methods. The influence of the size of particles of inert material added to the cement is also of great consequence, and a proper mechanical grading of the sand used in mortars is recognized as vital. The presence of clay in this sand, or the addition of clay alone to cement, come under this category, and have occasioned a great deal of discussion (8, 32, 33, 110).

A comparison was made of the permeability of 1:4 mortar of Portland cement, when used in its ordinary condition, and when screened through a number 200 sieve.

TABLE 3

Permeability of 2-inch Cubes, Age 28 Days, Subjected to 80 lbs. Pressure

Cement	Temperature of water. Deg. Fahrenheit		Grams of water passing per hour		Number of tests
			Unscreened	Screened	
A	66	68	22	33	5, 6
B	68	68	25	2	6, 6
C	68	68	29	Trace	6, 6
D	68	68	331	81	5, 6
E	64	64	27	Trace	5, 6
F	64	64	31	2	6, 6
G	64	64	5	0	3, 6
H	68	72	6	Trace	5, 6
I	68	68	71	0	6, 6
Average			61	13	

The marked decrease in permeability resulting from the use of finer cement in mortar demonstrates that in impermeability, as in strength, the finest particles are the most active factors.

Mechanical agitation when water is added.—Increased working should weaken a cement after a certain maximum point is passed. In order to establish this point, the effect of prolonged working was investigated. It was necessary to use a mix of fluid consistency, in which, for obvious reasons, the final set would not under normal conditions take place during the time over which the experiments were extended.

Two grouts were employed: one in which cement was mixed with 50 per cent of its weight of water, and one in which an equal weight of water was used. The different tests were run respectively for periods from one minute to five hours, and they were mixed in a motor-driven stirring machine of the type common in chemical laboratories.

After the stated period of stirring, the grouts were poured into glass tubes and kept in a damp closet for the twenty-eight-day period. Cylinders exactly two diameters high were cut from the specimens and crushed in the compressing machine, two cylinders being crushed for each period, and the average of the compressive strengths being recorded.

TABLE 4

Twenty-eight-day Tests of Grouts Mixed for Varying Lengths of Time

Duration of mixing	Compressive strength, pounds per square inch, average of duplicate tests	
	50 per ct grout	100 per ct. grout
1 minute	5240	3095
15 minutes	5545	4725
30 minutes	5710	4955
1 hour	5875	4840
2 hours	6075	4320
5 hours	4775	4538

The effect of mechanical agitation, when thus prolonged, is equivalent to that of the use of excess water—the strength of the cement is progressively diminished as the working proceeds. It is noteworthy that the effect is only reached after a certain optimum period is passed. Before this time, increased working increases the strength. We may conclude that there occurs within this period a process which neutralizes the effect of hydrolysis; and this process is probably the formation of the network which constitutes the setting.

As will be seen later, the effect of excess water is to reduce the ultimate strength. The effect, then, of mechanical agitation must be to bring more cement into contact with water and, therefore, to increase hydrolysis. This is probably accomplished by stripping off the protective film of gelatinous material which envelops each cement particle when it comes into contact with water, which film regulates the hydration of cement and causes it to proceed in a regular manner. This film being stripped off, the cement is subject to the destructive action of hydrolysis.

Where more water is originally present, the destructive action is sooner attained, as will be seen by comparing the 100 per cent grout with the 50 per cent. Evidently, the setting process proceeds best at high concentrations, when the amount of water is low. This may be so regulated that the setting process will not take place at all, by using a large excess of water and much mechanical agitation, as has been repeatedly observed by the writer.

Setting time of cement in laboratory air and in damp closet.—The standard specifications for setting-time tests call for storing the specimen in the damp closet, whereas the tests as generally conducted in most laboratories are made in the open laboratory air. A series of experiments was made, for the purpose of noting the deviation from standard results caused by this departure from the rule.

TABLE 5

Setting Time in Laboratory Air and in Damp Closet

Cement	Time of set in minutes			
	Laboratory air		Damp closet	
	Initial	Final	Initial	Final
X	255	375	300	435
Y-1	120	360	300	450
Y-2	300	420	360	480
Y-3	240	360	285	420
Y-4	240	390	250	450

From these results, it will be seen that setting in a relatively dry atmosphere takes place in a shorter time than in a damp one; also that the setting time is more uniform under conditions of high atmospheric humidity.

At the same temperature, evaporation takes place more rapidly in the former case; and allowing a cement mix to stand in such a position that evaporation of the mixing water may readily take place is practically equivalent to the use of an insufficient amount of mixing water.

Effect of excess of mixing water on strength of concrete.—Concrete is often mixed so wet that, as it is filled into forms to a depth of several feet, the water rises above the concrete and throws out considerable laitance from the cement. The ease of mixing and placing very wet concrete is the constant incentive for its use. This practice, however, is followed by a great deal of deterioration of the concrete in strength.

The strength rapidly decreases with the increase in the quantity of water used in mixing. The visible effect of this weakening is the formation of laitance, which has little or no setting power or strength, and which represents the loss of an active part of the cement, since, as is recognized, the finer parts are more hydraulically active.

Tests were made by mixing concrete at normal consistency and shoveling one-half the batch into a tank containing three to four inches of water, the depth of concrete being about four inches. The water rose to about an equal depth above the concrete. In test No. 1, the concrete was allowed to settle in water four inches in depth for 30 minutes, when the excess of water was siphoned off and the remaining material poured into molds. In test No. 2, the depth of water in the tank was three inches, and the water was siphoned off immediately while in agitation. In test No. 3, the same process was repeated, except that the depth of the water was four inches, and the concrete used was somewhat leaner. Test No. 4 represents the direct qualitative effect of the addition of an excess quantity of mixing water without subsequent handling. All specimens were cylinders six inches in diameter and 12 inches high. The remainder of the batch of concrete in each case was poured directly into molds, and the specimens were broken at 28 days. The amount of cement lost was roughly ascertained where possible by filtering the siphoned water and weighing the amount retained on the filter.

TABLE 6

Effect of Excess of Mixing Water on Strength of Concrete

Test No.	No. of specimens	Proportions	Per cent of water	Strength at 28 days, pounds per sq. in.	Per cent of cement lost
1	3	1 : 2 : 4	8.2	1240	..
1[5]	2	1 : 2 : 4	8.2	760	..
2	3	1 : 2 : 4	8.2	1485	..
2[5]	2	1 : 2 : 4	8.2	770	10
3	3	1 : 2.33 : 5	8.2	1490	..
3[5]	3	1 : 2.33 : 5	8.2	315	12
4	3	1 : 2 : 4	8.2	1385	..
4	3	1 : 2 : 4	10.3	1155	..

[5] Specimens shoveled into water as described.

Evidently, then, the mere presence of an excess of water is sufficient to produce the weakening effect, independently of any actual removal of cement from the concrete. As may be seen from Nos. 1 to 3, the leaner mixes suffer the greater deterioration in strength.

Effect of excess of mixing water on permeability of concrete.—A parallel series of tests upon the permeability of concrete treated with an excess of water was made, in which the correspondingly numbered specimens were treated in the same manner. The cylinders cast from these batches were eight inches in diameter and six inches in length, and were cased in the standard manner for permeability tests. Three specimens were made for each test, and at the age of 28 days were submitted first to 40 pounds pressure for one hour, then to 80 pounds for one hour, without interruption. The flow recorded is in grams passing during the last ten minutes of test.

TABLE 7

Effect of Excess of Mixing Water on Permeability of Concrete

Test No.	Proportions	Per cent of water	Temperature of percolating water	Grams passing in last ten minutes	
				40 pounds	80 pounds
1	1 : 2 : 4	8.2	67° F.	0	0
1[6]	1 : 2 : 4	8.2	......	479	456
2	1 : 2 : 4	8.2	58° F.	0	0
2[6]	1 : 2 : 4	8.2	......	212	588
3	1 : 2.33 : 5	8.2	56° F.	0	21
3[6]	1 : 2.33 : 5	8.2	60° F.	1814	Not tested
4	1 : 2 : 4	8.2	67° F.	38	18
4	1 : 2 : 4	10.3	......	26	80

[6] Specimens shoveled into water as described above.

In the foregoing experiments, the decrease in strength and watertightness may be referred to the deteriorating influence of excess water upon the cement (16). It may of course be argued that the more marked effects obtained in series 1, 2 and 3 than in series 4 are due to the method of making the tests; that is, that a considerable proportion of the active cement was actually removed from the body of the concrete by siphoning off the supernatant water with its laitance.

Effect of excess of mixing water on the strength of neat cement.—With the idea in mind that the weakening effect was independent of the removal of cement (1), a further series of tests was instituted, using a neat cement of good quality. The cement was poured into a series of glass tubes in which increasing proportions of water had been put, the tests representing a series of grouts mixed respectively with 50, 75, 100, 150, 200 and 500 per cent by weight of cement of water. The tubes were shaken for one hour and then allowed to stand for 28 days. The cement settled into the bottom of the tubes in the order of its coarseness, the fine nebulous laitance settling last as a cheesy white layer of increasing thickness, as the percentage of water was higher. This layer was carefully trimmed off in preparing the test specimens.

On breaking out the cylinders from the tubes at the end of the test period, it was decided to cut each cylinder into two, each exactly one diameter high, carefully noting the respective position of each in the tube. On submitting these to compression it was seen that the direction of difference between the upper and lower layers was not constant, nor was the difference a significant one, so that it was considered legitimate to average the strengths.

It will be seen by the table below that, even without actual removal of any cement, the formation of laitance has a weakening action upon cement.

TABLE 8

Compressive Strength of Grouts Mixed with Varying Proportions of Water

Per cent of water	Crushing strength, lbs. per square inch, average of two tests. Age, 28 days
50	6855
75	5900
100	4500
150	3430
200	2960
500	1810

The effect of excess of mixing water is therefore seen to result in decrease of strength as the water increases. Whether the effect is a permanent one was the next question that presented itself. To settle this point, a new series was undertaken, in which a larger number of differing percentages was introduced, and in which the resulting strength at two periods was determined.

The cement was mixed with the stated percentage of water, and worked for two minutes, the drier mixes upon the table in the usual fashion, and the wetter mixes merely poured into the tubes and shaken. Paper mailing tubes were used, 2 inches by 48 inches, treated with molten paraffin and sealed with paraffined corks, so as to be absolutely tight. To obviate the effect of possible leakage, the whole series was stored in damp sand.

Cylinders two diameters high were cut from the specimens at the stated periods, each cylinder being cut as nearly as possible the same distance from the bottom, and care was taken to avoid including any of the soft cheesy top portion, the settled laitance.

TABLE 9

Compressive Strength of Grouts Mixed with Varying Proportions of Water, Over Extended Period

(Each result is the average strength of three specimens.)

Percentage of water	Compressive strength, pounds per square inch		Per cent gain in strength over 28 days
	28 days	3 months	
22	7076	7504	6
25	6174	5402	—13
30	4563	6030	32
38	3992	5059	27
50	2991	5312	77
75	2113	4078	93
100	1609	3544	120
150	1270	2379	87
200	1306	2579	97
500	399	1141	186

It is apparent from these figures that the effect of hydrolysis upon the strength of cement is a reversible one, at least to a certain extent, since the specimens in which an excess of water was used in mixing showed a greater recuperative ability at the longer period than the cement in which the normal amount of mixing water, in this case 22 per cent, was used.

Upon inspection, it was observed that the three months' specimens showed in each case much less laitance than the similar 28 days' specimens had shown, and it was considered probable that the laitance, in standing, had adsorbed free lime from the remainder of the cement, through the activity of the water permeating the mass, and thus reverted to the original condition of the cement, or an approach thereto. An analysis was accordingly made of laitance scraped off from the top of one of the 500 per cent water specimens and thoroughly washed by decantation. It probably represents a maximum condition in the hydrolysis of cement.

TABLE 10

Analysis of Laitance from 500 per cent Specimen

	As obtained from specimen	Treated with lime water
SiO_2	15.28	15.91
Fe_2O_3	2.28	2.42
Al_2O_3	3.98	5.82
CaO	26.96	36.67
MgO	2.86	1.28
SO_3	6.47	2.72
CO_2, H_2O, etc.	42.17	35.18

The normal ratio of silica to lime in unset cement may be considered 1 to 2.82. In this material we find the ratio 1 to 1.76. This indicates a great loss of lime; and it was thought possible, that, by adsorption of lime, this laitance might regain at least a part of its hydraulic properties. Accordingly it was digested for several days with lime water at laboratory temperature, filtered off, carefully washed with distilled water and dried, as was the previous sample, at 100° C. An analysis showed the results tabulated in the second column. The ratio of SiO_2 to CaO had changed to 1 : 2.30.

Besides direct metathetical reactions between the components of cement and the water solution which always surrounds a mass of hardening cement, adsorption of various materials from this solution is unquestionably always going on. Were the fine particles of cement inert chemically, this would still take place, by virtue of the enormous total surface which they must present. Clay, it has been demonstrated, has the property of adsorbing ions of CO_3 from solutions of carbonates, and of Cl from solutions of chlorides (10).

The laitance then may, by adsorption of calcium hydroxide given off from the cement adjacent to it, recover some of the lime lost by it. Whether the lime adsorbed restores the original status of constitution is of course mere speculation. The trend of the strength tests shows that this is probably not so, but that the adsorption is not entirely a reversion of the hydrolytic reaction; in other words, that "drowned" cement will probably never recover and attain to the strength it would have had with proper hydration.

Effect of the presence of clay and dissolved substances.—It is apparent that if the decreased strength be directly referable to the action of the excess water upon the cement, any means of preventing the access of excess water should prevent, if only to a degree, the destructive action. The colloidal nature of clay (6) has been utilized in the water-proofing of concrete, the principle of its action being the formation of continuous gelatinous films throughout the structure, which prevent the passage of water. Although the same problem is not presented in a grout that exists in finished concrete, it is probable that some blanketing action might occur upon the addition of clay to the mixed mass.

The point was investigated. To correct for the effect of absorption of part of the mixing water by the admixed clay, a consistency test was made upon a sample of cement to which 10 per cent of clay had been added, and it was found to require 4 per cent more water than the same cement used neat.

The clay mixes were accordingly gaged with 4 per cent more water than the corresponding neat cement mixes, and the following series of compressive tests was made:

Table 11

Effect of Clay upon Destructive Action of Excess of Mixing Water

(Average of two tests at 28 days)

Neat cement		Cement, 10 per cent of which was replaced by a fat clay (dried)	
Water, per cent	Compressive strength, pounds per square inch	Water, per cent	Compressive strength, pounds per square inch
50	5782	54	1282
75	3134	79	1328
100	2273	104	2577
150	1896	154	2156
200	1381	204	1320
500	514	504	No strength developed

If the action of saline solutions upon cement is to accelerate the hydrolysis of the latter, it would appear that the destructive action of excess water would be accelerated by the presence therein of saline substances in solution; also, it is legitimate to expect that the addition of clay restraining the hydrolysis due to excess water will in this case exert a similar influence.

The following experiments, parallel to the foregoing ones, elaborate this point:

Table 12

Effect of Clay upon accelerated destructive Action of Mixing Water Containing 5 per cent of Magnesium Sulphate

(Average of two tests at 28 days)

Neat cement		Cement, 10 per cent of which was replaced by a fat clay (dried)	
5 per cent solution of magnesium sulphate, per cent	Compressive strength, pounds per square inch	5 per cent solution of magnesium sulphate, per cent	Compressive strength, pounds per square inch
50	2196	54	2774
75	548	79	1608
100	1512	104	No strength
150	556	154	" "
200	No strength	204	" "
500	No strength	504	" "

From these two series of experiments, it is qualitatively apparent that the presence of clay does prevent a certain amount of hydrolysis. From the first series, it is seen that this effect only begins to show itself as higher percentages of water are present, which would indicate that the clay may have taken up much more water than the constituency test revealed, and that, in the relatively drier mixes with clay, the cement suffered in strength because of insufficient water. On the other hand, experiments at this laboratory in which clay was used, replacing up to 10 per cent of cement in normally gaged material, showed that no significant decrease in strength was thereby obtained; hence the loss in strength in the 54 and 79 per cent grouts cannot be due to this cause.

It is more probable that the colloidal nature of the added clay is brought into play more effectively at the concentrations in which increased strength is observed, and that the latter is due to the coagulation of the clay by electrolytes adsorbed at this optimum concentration.

The same result would obtain where additional saline material has been added to the mixing water, as in the series where a 5 per cent solution of magnesium sulphate was used. The clay here prevents the acceleration of hydrolysis by the magnesium sulphate through adsorption of part thereof, and possibly by coagulating, forming an impenetrable barrier to the further action of water upon the remainder of the cement.

QUANTITY OF WATER THAT MAY SUBSEQUENTLY COME INTO CONTACT WITH THE SYSTEM

Permeability.—The solvent effect of water coming into contact with cement structures is best studied by the permeability test. This consists in forcing water through a mortar or concrete at a known pressure and observing the amount of leakage through the specimen. In detail, the specimen is generally made up in the form of a cylinder, and this is cased with a thick coating of neat cement on all sides but the bottom. The water, under pressure, is applied on the full cross-section of the specimen and forced through, dripping from the bottom, whence it may be collected.

With neat cement, of course, this method is inapplicable, because of the density of the material and the consequently enormous pressure necessary to force water through it, and moreover because of the mechanical difficulty in confining the water strictly to a passage through the specimen. The specimens tested, then, are lean mortars and concretes.

Although this test is designed to ascertain the resistance which these materials offer to the flow of water, it is evident that this resistance is not a constant quantity in the case under consideration.

The temperature and pressure of the percolating water being constant, the flow is diminished by cementing and clogging, and increased by erosion and solution; the quantity of water flowing through the mortar or concrete therefore is a function of the balancing of these processes.

Cementing may result from deposition of material originally in solution in the percolating water, or dissolved from one portion of the structure and deposited in another.

Clogging, similarly, results from material originally in suspension in the percolating water, and deposited in the pores of the concrete, or from material eroded from one part of the mass, either mechanically or as a result of solution of the attacking portions, and deposited in another part.

Erosion *per se* is a negligible factor; that is, the flow of pure water, carrying no suspended matter, will have very small mechanical effect upon an insoluble material. When the water is armed with suspended matter, however, its corrasive effects become proportionally magnified.

Solution is the most important factor in the process of percolation. Following the order laid down by Van Hise for natural rocks (104, p. 536), the basic materials removed are, firstly, the alkalies and, secondly, the alkaline earths, in the order calcium, magnesium. Since the alkalies exist in cement in the proportion of a little over one per cent and are not essential to the hydraulic properties or the strength, their solution is a matter of little consequence, except in that it may result in the formation of solutions which react upon the lime compounds and render their solution more easy of accomplishment. This reaction has been considered elsewhere. The removal of magnesium compounds proceeds at a lesser rate, although there is a greater percentage of them present; and their removal, in the main, may be dismissed as insignificant.

Since more than half the weight of fresh cement consists of lime, and since the strength of cement depends for the greater part upon calcium hydroxide, whether crystalline or adsorbed by colloids, the removal of calcium hydroxide from set cement is the factor of the greatest importance. Considering its solubility in pure water, the reversion of the hydroxide to the crystalline form tends to diminish its solubility, or from the other standpoint, its adsorption by a colloid tends to remove it from the solvent action of water. Unfortunately, however, it must be borne in mind that without exception, cement structures are nowhere subject to the action of pure water alone. From rain water, with its appreciable burden of dissolved gases and atmospheric salts, to the water of the ocean and the more heavily laden rock and mine waters, concrete structures are everywhere in contact with saline solutions of varying concentrations.

The effect of solution in percolation, then, is to a small degree dependent upon the solubility of the components in pure water. This effect diminishes as time goes on, because of the reversion of the soluble material to a less soluble form and because of the protection afforded by the insoluble portions of the system decreasing the exposed area of soluble material. The washing away of these protecting films will of course neutralize the second factor. The increased solubility of the components of set cement in solutions of various electrolytes is the more important element in percolation. Even a very dilute solution may have tremendous total solvent power, when the time element is considered. In fact, it may be that the action of a dilute solution will on the whole exceed that of a concentrated solution, by reason of the greater cementing and choking action of the latter, tending to diminish the quantity of water that may come into contact with the soluble portions. A dilute solution, therefore, with its more insidious attack, is probably more to be feared in the end than the strong brine.

Observation of the behavior of concretes and mortars during the permeability tests gives a clue to the balancing of these processes, whether there is a preponderance of cementing and clogging on the one hand, or of solution and erosion on the other. Attempts were made, in the experiments noted below, to study chemically the reactions involved, by periodical analyses of the percolating water. To this end nearly four hundred complete analyses of the effluent water were made. Upon tabulation of these it was observed that any deductions based upon them would be inconclusive, as the chemical composition of the effluent water represented one of a great number of variable factors that might occur at any point either within or without the concrete. The single qualitative generalization, that lime was removed from the cement at a diminishing rate, is the only permissible conclusion from the analytical data.

The original purpose of these tests was to ascertain the suitability of various aggregates for use in concrete, with reference to their stability in the presence of percolating water. At the conclusion of the series, it was found that the effect of water upon the various aggregates was practically negligible, during the period of observation, and that the action had been confined to the cement of the mortar. The aggregates had been protected from the action of water by the cement, it being probable, however, that a continuation of the tests would have revealed the action of water upon these rocks, when the protective influence was removed.

A series of sixteen aggregates was used, in as many concrete specimens. Since it is not the purpose of this report to discuss the relative suitability of these materials for concrete construction, but only to consider the action of the water upon the cement, two cases alone will be considered.

The rock was crushed and screened for each experiment to the same average effective size, corresponding to the following mechanical analysis:

TABLE 13

Mechanical Analysis of Aggregate used in Permeability Tests

Sieve	Square mesh opening, in inches	Per cent passing
1¾	1.89	100
1½	1.58	94
1	1.02	59
¾	.78	32
⅔	.59	21
2	.48	16
3	.30	6
4	.22	0

The sieve ratings are based on diameters of spheres of equivalent volume to the largest sized stone particles that will pass.

The fine aggregate was crushed quartz, the standard sand formerly used for cement testing, passing the No. 20 and retained on the No. 30 sieve. The cement used was a standard Portland of high quality.

The specimens were made in the laboratory's standard form for permeability test, cylinders eight inches in diameter and six inches in length, the proportions used being 1 : 3.5 : 6, this being found the richest mix practicable to secure the porosity required for the test. They were cased in neat cement, and connected suitably for subjection to the pressure of the city's water mains. Each specimen was protected from the direct flow of the water by a layer of one inch of clean coarse sand. The average pressure for the period of observation (52 weeks) was 22 pounds. The determinations of the rate of leakage were made weekly at first, and later every two weeks until the end of the test.

The data appended below represent observations on the rate of percolation of water through two of the specimens which present the greatest interest from the standpoint of this paper, this flow being recorded in grams passing in ten minutes. The aggregate used in one specimen was a hardened neat cement, crushed to the size stated, and used in place of the rock generally employed in concrete. The parallel specimen selected for comparison was one in which the aggregate was a crushed granite, which showed a low solubility in hydrochloric acid (2.66 per cent dissolved in one hour's treatment with 1 : 1 HCl).

Temperature records of the percolating water were not kept, since these tests represent a part of a larger series in which this would have been impracticable. The other aggregates tested showed results from which it was quite difficult to draw any legitimate conclusions as to the relative suitability of different rocks in concrete subjected to these conditions.

Concretes containing different aggregates.—A series of tests on concretes made up of different aggregates but with the same cements gave results which may be tabulated as follows:

TABLE 14

Flow in Grams of Water passing in 10 Minutes through Concrete Specimens subjected to continuous Water Pressure for 52 Weeks

Time	Pressure, pounds per square inch	Month	Grams passing in 10 minutes	
			Concrete with aggregate of crushed hardened neat cement	Concrete with aggregate of crushed granite
24 hours	25	January....	2111	60
1 week	22	February ..	836	31
2 weeks	22		662	26
3 "	20		626	40
4 "	25		570	60
5 "	22	March.....	603	62
6 "	20		530	50
7 "	20		1295	38
8 "	25		1127	40
10 "	25	April......	1310	45
12 "	26		870	25
14 "	24	May.......	997	36
16 "	24		985	28
18 "	20	June.......	973	32
20 "	17		639	20
22 "	20		792	40
24 "	17	July... ...	731	36
26 "	22		802	43
28 "	26	August.....	800	49
30 "	22		781	46
32 "	20	September.	763	50
34 "	19		115	Trace
36 "	26	October....	105	2
38 "	26		107	2
40 "	23	November..	110	3
42 "	25		93	2
44 "	22	December..	75	5
46 "	21		70	3
48 "	25		80	10
50 "	20	January....	73	7
52 "	20		78	7

Comparison of these two sets of figures indicates that the cement of the concrete is more attacked than the aggregate. In fact, the flow obtained in this specimen was the highest but one of a series of sixteen, and the total lime content of the effluent water was also the highest but one.

The visible effect upon examination of the interior of the specimens was a bleaching of the mortar, with evident solution of the cement. The original percentage of lime in the mortars was 12.8. Analysis of mortar from the granite specimen showed a content of 4.8 per cent, indicating that nearly two-thirds of the lime had been dissolved out. Further evidence of the loss of lime was found in the heavy white crust which formed on the exposed bottoms of the concrete specimens during the test. Small stalactites, quite soft to the touch, were abundant. The quantity of this deposit was not visibly different in the different tests.

The calculated loss in lime of the mortar was greater than the loss computed from periodical chemical analyses of the effluent water, and this is due to the fact that much of the dissolved lime was deposited upon the bottoms of the specimens as the stalactitic growth above mentioned.

There was no evidence that suspended impurities in the water had been carried into the interior of the concrete, and it is therefore supposed that the one-inch layer of sand by which the latter was screened from the direct flow of the water was an efficient filter for the purpose. The clogging action resulting from this source may therefore be dismissed as negligible.

It may be concluded from these tests that concrete of this density tends to protect itself automatically from the action of percolating water, so that, for the period investigated at least, the flow tends to diminish to a minimum. The action of the water seems to be confined to the cement of the mortar, leaving the aggregate relatively unaffected.

It is evident that, notwithstanding the utmost precaution in mixing concrete test specimens, wide differences in permeability may obtain in specimens mixed under the same conditions of handling and by the same workman, owing to structural differences in the resulting mass. However, the results obtained are fairly comparable.

The most sensitive test for the internal changes which the concrete has undergone during percolation is the resulting strength of the concrete.

Concretes containing different cements.—A series of tests was undertaken in which the specimens were made up in the same proportions, 1:2.5:6, using in each specimen the same coarse aggregate, a crushed granite, and the same fine aggregate, a standard quartz, but using different brands of cement. The specimens were stored in damp sand for a period of 28 days, then subjected to continuous water pressure of about

25 pounds for a period of 11 months. Parallel specimens were stored in damp sand during this period and allowed to attain their full normal strength. The table following shows the leakage and final strength of the specimens:

TABLE 15

Percolation through Concrete Specimens

Months of percolation	Brands of cement and grams of water passing in 10 minutes					
	A	B	C	D	E	F
½	146	286	63	164	76	230
1	155	125	22	179	16	82
2	56	70	90	167	11	85
3	37	47	52	161	11	82
4	72	28	37	65	7	45
5	71	12	31	15	17	39
6	68	28	34	11	26	33
7	57	46	14	6	16	21
8	40	43	12	2	5	11
9	....	....	....	....	....	....
10	13	7	10	5	4	14
11	8	13	10	1	2	19

TABLE 16

Comparison of Strength before and after Permeability Test

	A	B	C	D	E	F
Compressive strength of specimens at the end of period	770[7]	490	640	890	750	590
Compressive strength of untreated specimens, pounds per square inch	1080	1210	1230	1125	1220	1090
Loss of strength through percolation (per cent)	29	60	48	21	39	46

[7] One specimen crushed. Other results are average of two specimens.

Effect of the direction of flow through concrete.—Concrete seems to offer less resistance to the flow of water when the direction of the flow is parallel to the bed than when at right angles to it. A test covering this point was made with 8-inch cubes of concrete of the proportions 1 : 4 : 14, fine and coarse aggregate being a standard crushed bluestone.

TABLE 17

Rate of Flow in Gallons per Square Foot per Hour under 20-inch Head

Age of specimens, 67 days. Temperature of water, 64° F.	In specimen parallel to bed	In specimen perpendicular to bed
1st 2 minutes	740.96	164.14
2d "	585.28	159.54
3d "	636.31	163.49
4th "	535.53	158.33
5th "	549.10	157.93
Specimens immersed 24 hours, then retested :		
1st 2 minutes	665.38	182.46
2d "	642.77	177.54
3d "	662.80	177.54
4th "	641.15	177.06
5th "	659.57	173.67

In denser concretes, this effect was not found so marked. It will be noted that after storage following the first exposure to the effect of percolating water, these specimens appear to offer less resistance to the flow of water. This may be due to the fact that in lean concretes the proportion of capillary and subcapillary voids is smaller and that of supercapillary voids greater, and that cementing and clogging actions, which have their greatest effect in capillary and subcapillary passages, are not so effective.

The greater flow along the bedding planes has been observed in the case of rock, and is in all respects a phenomenon of the same nature. In the case of a stratified sandstone cited by King (51), the reason is advanced that no more water can pass the more open layers, when advancing across the bedding planes, than was able to pass those of the closest texture; whereas when the flow is along the bedding planes, each particular stratum carries water in proportion to the coarseness of its texture, uninfluenced by any other.

In the case of water percolating into a concrete tunnel this would tend to emphasize lateral percolation, and in the case of disintegration would exercise, in general, a localizing influence. It is not to be assumed that this is a rigid rule, inasmuch as a large number of factors, evidently, may neutralize this influence.

From these considerations, it will be seen that the solvent effect of water upon set cement is of high importance in considering the permanence of concrete structures, and that this solvent effect tends to diminish as the set cement ages. This is not the only way, of course, that water may afterwards affect the metamorphism of cement. It has been pointed out by Goldbeck (43) and by White (108) that the expansion or contraction of concrete depends upon whether the concrete remains wet or dry, and that the strains caused by alternate wetting and drying of concrete may be a more fruitful cause of cracks than temperature changes.

The presence of an optimum quantity of water is necessary, however, so that the proper reactions take place in the mass of setting cement, in order that the strength may increase normally.

QUALITY OF WATER AT FIRST ADDED

Compressive strengths of neat cements gaged with various solutions.—A normal Portland cement was mixed with the proper quantity of water (21 per cent by weight) in which was dissolved, in the different tests, varying concentrations of the salts indicated in the subjoined table. The cement was worked for one minute, and the plastic mass was tamped into glass cylinders approximately one inch in diameter, with the utmost precaution to avoid all air bubbles and at the same time to subject all specimens to the same pressure.

TABLE 18

Compressive Strengths of Neat Cement Mixed with Solutions of Various Salts

(Age of specimens, 28 days. Average of two determinations)

Mixes	Pounds per square inch	Gain or loss, per cent
1. Distilled water	7330	
2. 25% rock water[8] diluted with distilled water	6340	−14
3. 50% do.	6495	−11
4. 75% do.	6870	− 6
5. Rock water alone	5605	−23
6. 2% sodium chloride solution	6675	− 9
7. 4% do.	5815	−21
8. 6% do.	5065	−31
9. 8% do.	4215	−43
10. 10% do.	5285	−29
11. Saturated solution of calcium sulphate (± 0.2%)	7025	− 4
12. 0 2% solution of calcium chloride	6960	− 5
13. 0.2% solution of magnesium sulphate	6680	− 9
14. 0.2% solution of magnesium chloride	5595	−23
15. Equal parts of 11 and 12 ($CaSO_4$ and $CaCl_2$)	6565	−10
16. Equal parts of 13 and 14 ($MgSO_4$ and $MgCl_2$)	7355	+0.6
17. Equal parts of 12 and 13 ($CaCl_2$ and $MgSO_4$)	5810	−21
18. Equal parts of 11 and 14 ($CaSO_4$ and $MgCl_2$)	6200	−15

[8] This water contained: CaO, 1177 parts per million.
MgO, 226
SO_3, 408
Cl, 4360

The glass cylinders containing the cement were then stored in a damp closet for 28 days, when the cylinders were broken out, and two specimens, each exactly one diameter high, cut from each cylinder. These were put into water for a few hours, so that they might be in the moist state when crushed. The cylinders were kept in the damp closet instead of being stored under water, to avoid leaching out the salts contained in the mixing water, thus obtaining the maximum effect of the dissolved salts.

It will be noted that there is a decided loss of strength in all but one case (number 16). This particular case may be explained by the probable formation of an oxychloride, by the magnesium chloride and the magnesium hydroxide liberated by the action of the magnesium sulphate upon the calcium hydroxide of the cement. The oxychloride formed from these two materials has a tensile strength far superior to that of Portland cement itself, and its presence probably counteracted the destructive action of the salts upon the cement. It is probable, however, that, at longer periods, this increase would disappear and become a decrease. Otherwise, the presence of saline matter dissolved in the mixing water seems to have a decided deleterious effect upon the strength of cement. This point is of marked importance in construction, inasmuch as the problem of mixing water is often solved by using the water nearest at hand, without inquiry into its qualities.

It is the custom to specify that the water used in mixing concrete shall be free from oil, acid, strong alkalies or vegetable matter (77); but such a specification does not cover the case in point, and the presence of large quantities of dissolved salts in water used for construction is easily overlooked. In concrete construction, it is of the utmost importance that the water which may be used in mixing be additionally subjected to such tests as will reveal either its mineral content or its action when mixed with cement and possible subsequent attack thereon.

The action of sodium chloride appears to be nearly directly proportional to the amount employed. This salt is used in mixing water for construction carried on in cold weather, in order to prevent freezing of the deposited concrete. Its effect upon the strength of cement, if used in excessive quantities, is, as has been shown above, likely to become a serious matter. Under the conditions of construction which generally prevail, however, much of the salt may be leached out of the mass. The results above represent a condition of maximum attack.

Dieckmann (25) recommends the use of from 1 to 2.5 per cent of salt for concrete to be laid in cold weather, but states that percentages larger than this cause a marked decrease in the strength.

Effect of gaging with various solutions upon the strength of mortars afterward stored in water.—The above tests do not show, of course, a normal condition, since no water came into contact with the cement after it had set. Working with more porous material, a 1 : 3 mortar, so that in storage a heightened subsequent water action might take place, the following results were obtained:

TABLE 19

Effect of various Salts dissolved in the Mixing Water, upon the Strength of 1:3 Mortar

(Sand, screened Cow Bay. Specimens stored in damp closet for 24 hours, then continuously in water for the rest of period)

Mixes	Compressive strength, pounds per square inch			Number of specimens
	7 days	28 days	3 months	
Water	815	1475	2600	1,3,3
1% solution of $Al_2(SO_4)_3$	1005	1185	1805	3,2,1
2% do.	945	1310	2170	3,3,3
1% solution of Na_2SO_4	1010	1520	2420	3,3,3
2% do.	885	1240	2100	1,3,3
1% solution of $MgSO_4$	910	1625	2145	2,3,3
2% do.	865	1410	2115	2,3,3
1% solution of $ZnSO_4$	935	1595	2710	3,3,2
2% do.	1090	1580	2500	3,1,2
1% solution of $FeSO_4$	930	1605	2670	3,3,3
2% do.	840	1490	2710	2,1,1
1% solution of NaCl	1105	1385	2000	3,3,3
2% do.	1000	1035	1685	2,3,3
	Tensile strength, pounds per square inch			
	7 days	28 days	3 months	
Water	179	272	326	5,6,6
1% solution of $Al_2(SO_4)_3$	208	272	321	6,6,6
2% do.	193	262	340	4,6,5
1% solution of Na_2SO_4	216	290	354	6,6,6
2% do.	205	300	343	4,6,6
1% solution of $MgSO_4$	194	260	317	3,6,6
2% do.	185	246	283	4,6,6
1% solution of $ZnSO_4$	126	263	315	2,5,6
2% do.	205	272	319	3,6,6
1% solution of $FeSO_4$	201	266	314	5,6,6
2% do.	184	258	311	5,6,6
1% solution of NaCl	211	261	310	6,6,6
2% do.	224	279	310	5,6,5

The general conclusion that may be drawn from these values is that the effect of electrolytes in the mixing water, when the cement is afterwards subject to immersion in water, is to increase the strength at the early periods (7 and 28 days), but later to depress it (15). In general, the more concentrated solutions give a greater depression of strength. The early increase in strength is probably due, in the presence of an optimum quantity of water, to additional cementing or void-filling material precipitated in the pores of the mortar by reaction between the added electrolytes and the solutions resulting from the action of water upon cement. This deposited material may, in its later history, revert to a soluble form and be washed away, leaving abnormal voids, or else in its growth may disrupt the cells it occupies, in either case reducing the strength.

Effect of gaging grout with rock waters.—In grouting deep tunnels, the question has arisen as to the advisability of using the rock water at hand when fresh water was inaccessible. The water available in the instance in hand was an effluent from a shale bearing a small proportion of pyrites, and when it issued from the rock face it contained a quantity of dissolved hydrogen sulphide. As none of the water was immediately available for a laboratory test, an artificial mixture was made up, in which the quantities of dissolved salts and hydrogen sulphide occurring in the natural water was purposely exaggerated, to obtain accelerated effects.

TABLE 20

Analysis of the Artificially Mineralized Water

	Parts per million
H_2S	891
CaO	1764
MgO	1461
SO_3	1948
Cl	2920

A grout was made up according to specifications, using a normal Portland cement, and Cow Bay sand with 100 per cent passing 10 sieve, 75 per cent passing 40 sieve; in the proportions 1 : 1½ with 35 per cent of liquid. The wet mix was poured into glass cylinders, kept 24 hours in air until set had developed and immersed in water.

Four sets of three specimens each were made, the first set mixed with 35 per cent of distilled water; the second, 35 per cent of the water above mentioned; the third, 35 per cent of a 10 per cent dilution of this water, and the fourth, 35 per cent of a 1 per cent dilution.

No discrepancy was observed in the setting time, as all the specimens developed a fair set within 24 hours. The grouts mixed with the undiluted sulphide water turned a dark green, but otherwise no change was noticed in these or any other specimens. Three cylinders one diameter high were cut from each set of specimens, and, after storing 28 days in distilled water, were crushed.

Table 21

Compressive Strength of Grout Mixed with Different Proportions of Water Containing Hydrogen Sulphide

(Average of three specimens, age 28 days)

Mixes	Pounds per square inch
Distilled water	1424
Undiluted sulphide water	1608
10 per cent of sulphide water, 99 per cent of distilled water	2088
1 per cent of sulphide water, 99 per cent of distilled water	1110

Apparently, considering the average of the last three values, water of this composition will have no evil effect at 28 days upon the grout with which it is gaged.

Three series of tests were undertaken, in which a 1:3 mortar of Ottawa sand and a cement of good quality was mixed with Croton water, and with two typical rock waters encountered in tunnel work.

Table 22

Analyses of Rock Waters

	Parts per million	
	E	W
CaO	85	943
MgO	159	156
SO_3	73	172
Cl	1380	3420
Total solids	2978	7929

The normal amount of water was used to mix the mortars in each case, and the briquettes were stored in the damp closet over the stated periods.

Table 23

Tensile Strength of 1:3 Mortars Mixed with Various Saline Waters

Mixed with—	Pounds per square inch			Number of specimens in average
	7 days	28 days	3 months	
Croton water	302	322	344	6, 5, 6
Water E	297	343	363	6, 6, 6
Water W	296	335	383	6, 6, 6

As was found in the case of the grouts last mentioned, waters of this general concentration do not appear to affect the strength of cement mortars with which they are gaged, and the probabilities are that no serious effects will result from this cause alone.

QUALITY OF WATER THAT MAY SUBSEQUENTLY COME INTO CONTACT WITH THE SYSTEM

Theoretical considerations.—The action of dissolved salts in water that comes into contact with concrete, where such action is deleterious to the concrete, has been carefully studied by a large number of investigators (68, 81, 96, 112). Of the salts which have been found injurious, magnesium sulphate and magnesium chloride seem to have the greatest effects. What concentration of dissolved salts is necessary in order that disintegrating effects shall manifest themselves cannot be definitely stated. This is a field problem and is subject to wide variations under different conditions.

A water containing relatively little dissolved material, acting under favorable conditions of porosity, pressure and wide temperature changes upon one concrete, may accomplish failure of the structure; while another water, of high saline content, meeting a dense, impervious concrete, not forced through the mass by pressure and under conditions of small temperature change, may have practically no action. Manifestly, unless these varying conditions are taken into account, it is unscientific to draw any conclusions regarding the attack of different waters or the resistivity of different cements.

It may be laid down as a basic principle, however, that the denser a concrete, other conditions being equal, the greater its resistance to the attack of saline waters (10, 41, 57). The alkali waters of the Western states have given a great deal of trouble in concrete construction. Most experimenters conclude that their action upon concrete is in the main mechanical and due to the disruptive force of crystallizing or efflorescing salts deposited in the pores by intermittent submergence and drying out (30, 38, 49, 56).

Of course, as has been pointed out, action of this sort is not confined to concrete, and any material of construction possessing porosity is liable to a similar disintegration. The remedy, therefore, is to prevent the penetration of the saline solutions by the employment of courses of permanent, impenetrable materials, preferably asphaltic layers.

Where the attack is not mechanical but chemical, this remedy is also applicable. Unfortunately, there are examples of construction which are exceptions, and, in these, some change in the chemical or mechanical constitution of the cement is the only way to prevent decomposition. In concrete block construction, where the blocks may be made long before they are actually put into the structure, it is found of great advantage to allow them to harden in air or in damp sand, and so permit to a great extent the carbonation of the lime compounds. Some investigators claim excellent results from this method (41, 55).

As to the modifications in the constitution of the cement that will combat the action of saline solutions, there is a great disparity of opinion, which possibly is based upon lack of standardization of experimental conditions. It is generally conceded that high silica cements are best suited for the purpose (7). The use of puzzolan cements, or of additions of puzzolan to the cement in use, is also well recommended (7, 37, 66); and the addition of clay, burnt or dehydrated, finds favor with some (7, 75). As to the lime content of the cement, opinions are divided whether it should be high (5, 41) or low (92).

Cement of greater density (57) and cement ground to a greater fineness than usual (72) are favorably commented upon. The subject, because of its great complexity and because of the questionable value of laboratory results, is at present in a chaotic state. The length of time that must elapse before judgment may be passed upon the permanence of a material under these conditions and the corresponding newness of the field of Portland cement render present conclusions largely a matter of speculation.

Effect of storage in various saline solutions upon the strength of mortar.—In order to study the relative resistance to saline solutions offered by cements varying in chemical composition and in fineness of grinding, a series of 132 2-inch mortar cubes was made up, in the proportion of 1:3, with standard Ottawa sand, the cements used being

A. A high silica cement
B. A low silica cement
C. A cement of ordinary composition, sifted and remixed so that 98.8 per cent passed the 100 mesh sieve and 88.6 per cent passed the 200 mesh sieve
D. The same cement as C sifted so that 92 per cent passed the 100 sieve and 75 per cent passed the 200 sieve

TABLE 24

Analyses of the Cements Used in Tests with Saline Solutions

	Per cent		
	A	B	C
SiO_2	23.50	19.74	22.99
Fe_2O_3	2.36	2.75	2.42
Al_2O_3	7.28	8.77	6.79
CaO	62 18	60.86	60.84
MgO	2.29	2.86	4.14
SO_3	1.11	1.39	1.76
CO_2H_2O, alkalies	1.28	3.63	1.06

The cubes were stored 24 hours in the damp closet, and then transferred to the solutions mentioned in the following table, three cubes to each liquid, and there stored for three months, then broken.

TABLE 25

Compressive Strength of Mortars Stored for Three Months in Various Saline Solutions

(Each value is the average of three determinations)

Storage medium	Pounds per square inch							
	High silica	Gain, per cent	Low silica	Gain, per cent	Finely ground	Gain, per cent	Coarsely ground	Gain, per cent
Croton water	2217	......	2462	......	2134	......	2066	
Sodium sulphate, 5%	2267	2	2090	−15	3266	53	2273	10
Sodium sulphate, 10%	3264	47	2035	−18	2223	4	2262	9
Magnesium sulphate, 5%	3244	46	1787	−28	2233	5	2759	33
Magnesium sulphate, 10%	2604	18	2646	7	3003	42	2489	20
Sodium chloride, 5%	2365	7	1785	−28	2305	8	2695	30
Sodium chloride, 10%	1778	−20	2019	−18	2968	40	2044	−1
Magnesium chloride, 5%	2331	5	1827	−26	2731	33	2305	12
Magnesium chloride, 10%	1757	−21	1769	−28	2570	20	2269	10
Calcium chloride, 5%	2653	19	2516[9]	2	2219	4	1808	−13
Calcium chloride, 10%	2224	0	1994	−19	2042	−4	2238	8
Average gain (per cent)	....	10	....	−17	....	20	....	12

[9] Average of two determinations.

The general deductions from these experiments for the period covered are that the high silica cement, notwithstanding its slower rate of hardening, resists the action of these dissolved salts better than the low silica cement, and the finely ground cement better than the coarsely ground. Moreover, with the concentrations used, the stronger solutions in nearly every case had a more destructive effect upon the strength of the mortar than the weaker.

The strengths here obtained by storage in salt solutions are in general decidedly greater than those obtained by storage in fresh water. Examination of the cubes, when removed from the solutions at the end of the test period, revealed under a lens that the exterior was being attacked, minute pittings being quite distinct.

The strength attained by these specimens may be considered as a resultant of the balancing of two effects: the deposition of crystallized or precipitated material in the voids, which by packing the spaces with solids will increase the compressive strength; the creation of additional voids by direct solution or by the disruptive effect of metathetically produced material. It is probable that the disintegrating effect for these concentrations is reached considerably beyond three months' exposure. From the increases in the compressive strength, it is likely that at this period a great deal of crystallization or precipitation has proceeded, overbalancing in the main the disruptive effects. This is a general deduction, and single instances are notable in which the reverse holds good.

In the case of the finely ground cement, the density of the mortar made therefrom has prevented the disruptive effect to a greater degree; and thus the deposition, while not necessarily as much as in the coarser cement mortars, has had a more marked effect in increasing the strength.

Effect of storage in rock water upon the strength of lean cement mortars.—A series of briquettes of 1 : 4 Ottawa sand mortars was made up, using a normal Portland cement of high quality. The mix was made lean purposely to accelerate whatever disintegrating effect might occur. Batches of the briquettes were stored in bottles in the laboratory for the 7-day and 28-day tests, and additional series were stored in the field, for the longer tests, at stations where the waters in question were encountered. The field series were stored in running water, and the action upon these should be more severe than upon the laboratory specimens stored in still water. In each case a parallel test was made by storing a series in pure drinking water.

TABLE 26

Tensile Strength of 1:4 Mortars, stored in Rock Water

Water	Strength, pounds per square inch								Specimens in average
	Stored in laboratory				Stored in field				
	7 days	Gain	28 days	Gain	3 mos.	Gain	6 mos.	Gain	
Drinking..	211	......	297	......	320	......	324	......	12,12,6,6
"A"	220	+4%	312	5%	323	1%	247	−24%	12,12,6,6
"B". ...	203	−4%	287	−3%	313	−2%	303	− 5%	12,12,6,6
"C".....	221	+4%	288	−3%	340	6%	328	1%	12,12,6,6

TABLE 27

Analyses of Rock Waters in Previous Experiments

	Parts per million		
	A	B	C
H_2S	44		
SiO_2	20	15	4
$Fe_2O_3+Al_2O_3$	7	5	4
CaO	284	399	87
MgO	124	118	38
SO_3	727	353	31
Cl	826	546	270
CO_2, Alkalies, etc......	949	459	317
Total solids.......	3037	1895	751

The drinking water used to store the blanks contained in neither case more than 100 parts per million of total solids.

The most consistent reduction of strength, although a slight one, is observed in the case of water B, a fairly typical sulphato-chloride water according to Clarke's classification (18, p. 190). A strikingly high and sudden reduction occurs at six months in water A, a sulphate water charged with hydrogen sulphide, while water C, a chloride water, shows no marked reduction of the strength, which, however, may be due to a low salinity.

The six-month briquettes stored in water A showed superficially much minute pitting, due to the removal of the sand grains, presumably by solution of the matrix of the cement. Two sections were cut from one of these briquettes, one transverse and one longitudinal, in the hope of discovering whether any replacement of the original material by sulphates or sulphides was going on. The microscopic examination did not reveal anything of the sort, the sections being in all respects similar to sections cut from the briquettes stored in drinking water. It was concluded therefore that the loss of strength was due to actual removal of material by solution rather than by replacement with material which would cause disintegration through a discrepancy in volume.

The legitimate general deduction from these tests is that, over the period of experiment, the effect of these waters is greater in void filling by crystallization or precipitation than in disintegration by solution or disruption.

The void-filling material, if of a stable nature and not likely to return into solution, should be in a measure a protection against the further entrance of the saline solutions. It has been mentioned that this property has been suggested of magnesium hydroxide (70). Probably upon this possibility is based the reported effect of chemically inert fine materials, added to the cement for protection against such destructive action.

SUMMARY OF EXPERIMENTAL RESULTS

1. Increase of temperature of the water with which cement is mixed causes acceleration of the set up to a certain maximum temperature, then a retardation.
2. Storage in cold water, without freezing, retards the hardening of neat cement, and that of mortars more.
3. Increase in the proportion of fine particles in a cement decreases the permeability of mortar made therefrom.
4. Mechanical agitation increases the strength of cement up to a certain maximum time; after which, if continued, it reduces it.
5. The setting of cement is accelerated by dryness of the atmosphere.
6. An excess of mixing water progressively reduces the strength of cement. This effect is partly reversive of itself, and the reversion may be increased by additional colloidal material in the original cement.
7. Water percolating through concrete dissolves the lime of the cement chiefly, and this effect tends to neutralize itself by "healing."
8. Percolation through concrete preferably follows the bedding planes.
9. Salts in solution in the mixing water tend to lower the strength of cement. This effect may be neutralized by precipitation in the pores.
10. Storage in saline water affects low silica cements more than it does high silica, and coarsely ground cements more than it does finely ground cements.

General Conclusions

In general, the metamorphism of Portland cement represents on an accelerated scale the processes which occur in natural rocks. The acceleration is of course due to the ease with which water has access to the finely comminuted particles in the initial stages of metamorphism. Many of the minerals found in natural rocks, when ground as finely as, or finer than Portland cement, undergo vastly accelerated reactions in the presence of water; colloidal bodies are thereby produced, and the water is rendered alkaline (18).

The end product of prolonged water action on Portland cement bears a striking qualitative similarity to the end product in the kaolinization of feldspars. The same transformations evidently occur in both cases,—the alkalies and the lime are abstracted, and the water and alumina contents increased. The exceeding fineness and high adsorptive power of the resulting products are also similar. The action of water on nearly all silicate minerals is, in effect, a repetition of this process.

The peculiar adsorptive properties of colloidal bodies render these liable to coagulation. As has been pointed out in preceding pages, much of the cementing material of conglomerates and sandstones, except where calcitic, may have its origin in a similar phenomenon.

On a natural scale, the action of water is greatly retarded, because of the larger size of the bodies acted upon, and the consequent paucity of surface upon which water may exert its influence. When Portland cement has properly undergone its initial metamorphism, the setting process being complete and the hardening process in great part so, it approaches the condition of a natural metamorphic rock, and activities towards its further change are katamorphic and vastly slower in their results than the initial changes. The component particles have now become consolidated and the surface offered to the action of water is minimized. Of course, this is truer of neat cement than mortar and truer of mortar than of concrete, these being in the order of increasing porosity.

The hypothesis that crystal formation is responsible for the strength of hardened cement is not so complete and satisfactory as the colloidal hypothesis just referred to. In a compact mass, the growth of crystals can hardly be considered anything but an element of weakness. As has been shown by the foregoing results, the effects of varying some of the conditions of the action of water upon cement are best explained by considering the hardening a coagulative process rather than a process of crystallization.

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THE PHYSIOGRAPHY OF THE PERUVIAN ANDES

WITH NOTES ON EARLY MINING IN PERU

BY

V. F. Marsters

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THE PHYSIOGRAPHY OF THE PERUVIAN ANDES

WITH

NOTES ON EARLY MINING IN PERU

BY V. F. MARSTERS

(*Presented in Abstract before the Academy, 5 February, 1912*)

CONTENTS

INTRODUCTION

So far as I am aware, very little has been written relative to the physiography either of the coast or of the Peruvian Cordillera. As preliminary to the presentation of a few observations on the above subject, I wish to summarize very briefly a list of the early pioneer geographers, geologists and naturalists who have visited the Peruvian shores and have published observations relative to the subject in hand.

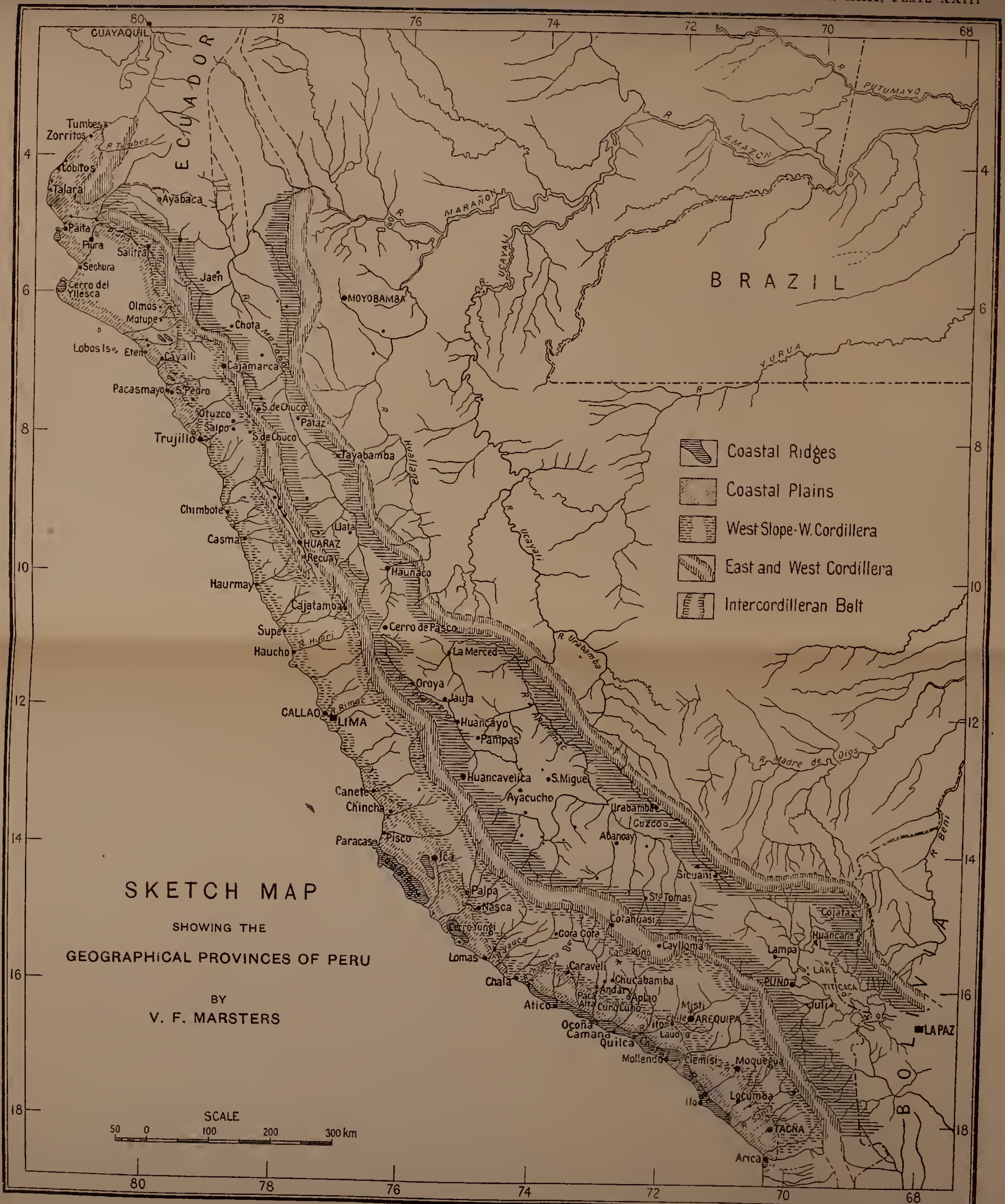
Darwin was among the first to record observations relative to the coast of Peru. He noted the many old shore line beaches now standing at various elevations above the present sea level. The same facts were noted later by D'Orbigny. The occurrence of "kitchen middens" was recognized at various points. They appeared to be associated with the ancient beaches, thus suggesting that elevation had actually taken place since the accumulation of the shell heaps. The writer has seen between the mouth of the Rio Grande and Lomas as many as five well-defined old shore lines or beaches occurring in succession, the highest one being approximately some sixty feet above sea level.

I find also that a geographical map of a portion of southern Peru, together with a portion of Bolivia and Chile, has been prepared by one Mr. Pentland, but to date I have been unable to locate it or any of his written contributions on the geography of the above section.

Pissis and D'Orbigny were the first to contribute detailed geological and indirectly geographical information concerning southern Peru and the adjacent republics. Both these men constructed cross sections of the Peruvian and Bolivian Andes, the section starting at the coast near Tacna and ending on the east slope of the East Cordillera to the east of La Paz. Some years later Forbes went over the same ground and likewise constructed a cross section. While the same type of relief is expressed in all these sections, the classification of the formations, based in part upon lithological and in part upon paleontological data, differs very widely in each case. The sections prepared by these men may be seen in the now rare publication of the Geographical Society of La Paz, Bolivia.

Among the later pioneer naturalists who did much serious work in Peru was one Señor Raimondi, an Italian by birth. He came to Peru, bringing with him the training of an Italian institution and that profound interest in his field of investigation that is always sure to produce invaluable results. Raimondi was the Agassiz of Peru. Among his first efforts was the preparation of a topographic map of Peru; and to date it is the only map possessed by the republic and officially accepted by the government. The writings of Raimondi are likewise voluminous. While collecting his map data he likewise accumulated a mass of information relative to the geology, mineralogy, zoölogy and botany of the entire country. The results of his investigations were published in a series of volumes by the Peruvian government.

Another source of information is to be found in the publications of the Cuerpo de Ingenieros de Minas, a department of the government instituted by Sr. José Balta for collecting information concerning the natural resources of the republic, such as mines and mine production, the



SKETCH MAP

SHOWING THE

GEOGRAPHICAL PROVINCES OF PERU

BY

V. F. MARSTERS

geology of mining districts, data concerning irrigation projects, underground waters, etc. More than two hundred bulletins have been published by this department. While much information exists in the series of publications, it is unfortunate that no attempt has ever been made to correlate it with a view to preparing at least a preliminary geological map of the more important mining centers of the republic. So far as I am aware, the only attempt to correlate the formations in distinct parts of the republic was recently made by Dr. G. Steinman for the Cordillera and by the writer for the formations of the coastal plains as they appear in northern, central and southern Peru. Hence we may say that, while there are sources of information relative to the geology and geography of the Peruvian Cordillera, in no publication, so far as I am aware, has any attempt been made to give even a skeleton outline of the probable physiographic history of any section of the Andes.

Let us now see if, from the information to be gleaned from the early writers and especially the map of Raimondi, combined with the observations of the writer, we may be able to get a concise picture of the geography and at least a glimpse into the geology of a portion of the Peruvian Andes.

The Republic of Peru occupies an area approaching 2,000,000 square kilometers; it extends from 0° to 20° S. latitude and from 64° to 84° W. longitude; its coast line is approximately 1,500 miles long, and it possesses all the varieties of climate from typically tropical conditions in the north to cold temperate in the south and in the higher parts of the Andean Highlands. One need not go beyond the confines of the Inca Republic to find any of the variations between the extremes mentioned. One may leave Lima under a semi-tropical sun and, in the course of a few hours by rail, be riding over a snow-covered Puno. As soon as he reaches the montaña, or the wooded part of the eastern slope of the east range, he passes immediately into warm temperate and tropical climates.

Topographic Provinces of Peru

The distinct topographic and physiographic provinces of Peru are well defined. They may be summarized as follows:

1. Coastal Plains.
2. West Slope and West Range of the Andes.
3. Highland Plateau, or Intercordilleran Belt, and its associated secondary ranges.
4. Eastern Range.
5. Eastern Slope and Lowlands.

COASTAL PLAINS

The distribution of the coastal plains may best be seen in the accompanying sketch map. They occupy three sections, which may be designated as the northern, central and southern divisions.

The northern division begins in the region of Tumbes, near the boundary of Peru and Ecuador. It extends along the coast to the south, reaching its maximum width in the cross section between Cerro del Yllesca and Salitral. From this point to the south, it grows narrow quite rapidly and finally ends at Salaverry.

Going still farther south, we find but few remnants of what must have been the inner edge of the coastal plain tucked away in partly drowned valleys within the limits of the western slope. Between these valleys, the formations composing the foothills of the western range now occupy the present shore line and continue to do so, until we reach the region of Canete. Here the coastal plain again makes its appearance. It can be traced to a point just to the south of the mouth of the River Yauca. Here again the foothills of the western slope reach the present shore line.

If we were to travel along the shore line from Yauca to the south, we should be very much inclined to believe that, as far south as Ocoña, the actual foot-hills of the Cordillera again formed the present shore line. This, however, we find not to be true. Should we pass up the Valley of the Atico, we should find a belt of country some fifteen to twenty miles wide occupied by Tertiary and post-Tertiary deposits, similar to those we have seen to the north but standing at a higher altitude. They are deeply cut by the streams coming from the west range of the Andes. It is not improbable that this belt may extend to and beyond the Valley of the Chaparra. Going to the south, we can trace the elevated coastal plain, where it is known under the various names of Paco Alto, Cuno-cuno, south of the Valley of Ocoña, Pampa de la Joya, south of the Valley of the Vitor, Pampa de Clemesi, south of the Tambo Valley, etc., and thus continues with decreasing altitude to the southern boundary of Peru and Chile.

One of the additional features of the coastal plain is the frequent occurrence of isolated hills and ridges near the present shore line. These are locally known as "morros." They usually stand at an appreciable elevation above the general level of the plain and hence form convenient landmarks for determining direction of travel to a given point.

With the exception of the section of the coastal plain to the north of the Valley of the Ocoña, the principle transverse streams have succeeded in cutting only deep narrow valleys, with very little available floor for agricultural purposes. The interstream spaces are barely scarred by insignificant tributaries, so that we have huge expanses of desert plain extending from valley to valley. As we approach Moquequa and Locumba, however, the elevation has been less, so that the rivers have made broader valley floors on which has been developed considerable grape culture, while, in the Valley of Sama, sugar cane forms the chief agricultural product.

Geologically considered, the coastal plains of Peru are composed of Tertiary and post-Tertiary sediments and lava flows, laid down on a post-Cretaceous surface, which at the beginning of Tertiary sedimentation had not been worn down to grade. This is proved by the number of half-buried hills now standing above the general horizon of the coastal plain, the so-called "morros" already referred to. In many instances, these hills merge into ridges and form what is known in Peruvian geography as "Cadena de la Costa," or coastal chain. Their distribution may be seen on the accompanying sketch map.

As might be expected of a coastal plain bordering a mountain range of such tremendous proportions and geologically young, it has undergone differential elevation to a great degree. In various localities, folding and faulting have taken place on a considerable scale.

In that section to the north of Paita where I have made some detailed stratigraphical studies, on account of the development of the Zorritos, Lobitos and Nigritos oil fields, it is calculated that not less than 3,000 feet of Tertiary sediments enter into the structure of the coastal plain. Some localities are rich in fossil gastropods and nautiloid forms. They are supposed to represent lower and middle Tertiary faunas.

It is interesting to note the fact that the oil-bearing localities so far developed are associated with the sections of maximum disturbance of the formations. The oil field of Zorritos is located on the eastern flank of a folded section, much of which is located beyond the present shore line. It is also in this section that we find the largest amount and most minute type of surface dissection. The folding of the Zorritos section may be traced to the northeast for some distance. In the interior to the southeast, the folding gradually fades out until we reach the flanks of Amotape Mountain, where its contact with pre-Tertiary formations is encountered.

Passing to the section of Lobitos, we find the same stratigraphical and structural relationships as noted in Zorritos. The area of maximum folding is near the present shore line. About Lobitos, the original surface of the coastal plain has been completely eroded away. To the north of the Lobitos field, we find the original surface forming an extensive plain some 300 feet above sea level and with its shoreward edge somewhat cut up by narrow, short valleys. Passing to the interior from Lobitos in the direction of the Amotape spur of the west range of the Andes, considered in its broadest sense, the evidence of folding, faulting, etc., rapidly disappears, until we approach the inner edge of the plain, where we find that the Tertiary sediments are upturned.

Following to the south towards Talara and Nigritos we find that while folding is much less accentuated than at Lobitos, it by no means disappears entirely. At Talara, however, we find another area of maximum disturbance, which extends to the southern end of the oil field now being operated by the London Pacific Petroleum Company. Following this section to the interior, we note, as in the preceding cases, a disappearance of the folding, until we reach a narrow belt adjacent to the Amotape Mountain, where the Tertiary strata are found to stand at a high angle and dip toward the northwest. I wish here to record another fact. The first oil springs noted in this region were located at the interior edge of the coastal plain at a point known as La Brea. A little later a residuum of petroleum was located on the playa near Nigritos. This was mined for some time by the Spaniards and prepared for painting the bottoms of their ships.

In the Chira Valley, we find the Tertiary occupying an arm-like extension or depression between the Amotape spur on the northwest and an edge of the foothills on the southeast. On the high plains to the rear of Paita, some 300 feet above sea level, there is a well-defined nonconformity between red clays with a marked tilt and a series of sands and conglomerates containing numerous fossils. Many of these resemble very closely the forms now living on the present shore. At various points between Paita and Piura there may be seen on the surface shells of exactly the same variety as are now living on the Pacific shore.

Just south of Paita we find a typical outlier of the western range sticking its higher points somewhat above the level of the adjacent plain. In the interior, the eastern boundary is located near Tambo Grande. It follows the general trend of the rivers Salitral and Serran (or R. Piura), or not far from the contact of the coastal plain deposits with the pre-Tertiary formations of the foothills. That is to say, the Salitral-Serran valley has been made by a longitudinal subsequent river, using the phraseology of Professor Davis.

The maximum width of this division of the coastal plain is attained along a line from Cerro de Yllesca to Salitral. Following the inner edge, we pass to the south through Olmos, Motupe, Patope and Cayalti. A very narrow belt then passes along the present shore line to the Pacasmayo

Valley. The Cerro de Yllesca forms another of those outliers that serve to break the monotony of the sky line as seen from the interior.

From the Tablazo de Paita, the elevation decreases somewhat in the direction of the Despoblado de Sechura and the Plain of Olmos, while a minimum uplift took place in the section through Morrupe, Chiclayo and Lambeyaque. As to the stratigraphy of the Sechura-Olmos area we can say but little. This is one vast plain, a typical desert, strewn with wind-blown sands, with here and there small depressions occupied with "salinas" or salt deposits, but so slightly dissected that data giving a clue to the stratigraphy are wanting. Sections, however, between the mouth of the Sechura River and Cerro del Yllesca, as exposed on the shore line, lead me to mistrust that beneath the sheet of recent accumulations over this vast plain there must exist a thick series of Tertiary sediments. Not a single morro of pre-Tertiary origin is to be found until we approach the region of Olmos. The accumulation of Tertiary sediments in the central parts of the desert may thus be very considerable.

As has been stated, the continuation of the coastal plain below Cayalti is represented by only a narrow rim, which, as we approach the Valley of Pacasmayo (the River Jequetepeque), again widens out to several kilometers. Here we find that the outliers of the foothills are quite numerous. An interpretation of the stratigraphy in this valley is difficult on account of the lack of good exposures. Sufficient evidence is at hand to suggest that the red clays corresponding with the lower part of the Paita section are present.

Following to the south again, but a narrow band of the plain bordering the shore line connects with the Valley of the Chicama and Santa Catalina. These valleys are probably filled in part with late Tertiary sediments, but later were littered up with much post-Tertiary waste, a phase of coastal geography to be discussed later. The southern extremity of the northern division ends at Salaverry.

The stretch of coast from Salaverry south to a point just south of Lima is largely occupied and confronted by the foothills of the Cordillera. Only the larger valleys have broad floors near the coast. Whether many of these contain remnants of Tertiary formations or not has not been determined by the writer. It is not improbable that during Tertiary time a fiord-like arm of the Tertiary Sea may have extended into the partially drowned valleys of the West Range. At all events, it is certain that a large amount of waste has very recently accumulated and spread over the lower stretches near the present shore line, presumably in post-Tertiary time. The valleys of Huacho and Chimbote are fair examples. Mention should also be made of the fact, that, in the upper portions of many of these partially filled pre-Tertiary valleys the recent deposits of sand, gravel and clay have again been attacked by the present streams and redistributed at lower levels. The same type of physiographic history is repeated in the valleys of the Rimac and the Chillon. The lower part of the Rimac Valley and the broad area where it is confluent with the Chillon have been aggraded by the deposition of an enormous sheet of fluviatile material. Lima, the capital of the republic, stands on the edge of this fluviatile plain. Whether Tertiary formations exist beneath the sheet of waste or not has not yet been determined.

Not until we reach the vicinity of Cerro Azul, Cañete and Chincha does the typical coastal plain again make its appearance. In the section through Chincha it has a width of some three or four kilometers. The transverse streams have incised themselves but slightly into the surface deposits. The formations thus far exposed here appear to be post-Tertiary waste, sands and conglomerates, undoubtedly deposited upon late Tertiary clays. The latter may be seen in sections at points between Chincha and Pisco to the south. These are regarded as the equivalents of the late Tertiary clays at the bottom of the Paita section. Folding and minute faulting may be seen at various points; the best exposures occur near Pisco. To the north of Pisco, the amount of Tertiary deposition may have been very considerable, but to the south, there is reason to believe that no great proportions were reached. The fact that a very large part of the shoreward area from Paracas to the mouth of the River Ica is occupied by outliers of the pre-Tertiary oldland, precludes, at least, the idea of Tertiary deposition on any great scale in that particular section. It was only between this broken line of hills or outliers and foothills of the west range that any great amount of Tertiary deposits accumulated. In the upper part of the Ica Valley, within the limits of the coastal plain, a very thick sheet of post-Tertiary waste was spread out on the Ica plains as far south as Ocacaje. To the west of Ocacaje, the best exposures of the light-colored Tertiary clays containing fossil fish are to be seen. These rest upon the eastern flank of the outliers already referred to and probably pass under the fluviatile plains in the upper stretches of the Ica Valley and plains. From Ocacaje south we may trace the plain across the Pampa de Huayuri to Palpa, San José and Nasca. To the south of the Rio Grande, we reach the Pampas de Yunga Colorado and Bella Union on the northwest side of the Valley of Acari. The plain finally ends at a point a short distance south of the mouth of the River Yauca. The Pampas de Yunga are separated from the coast line by Cerro Yunga, composed of pre-Tertiary formations, another outlier of the West Range. Some distance to the south of Cerro Yunga, the coastal deposits again form the shore line and continue with but little interruption to the southern terminus of the central division. From the Pampas de Yunga, with an elevation of some 700 to 900 feet above sea level, the surface gradually descends, until, at Lomas, it passes beneath sea level. To the interior from Lomas, where the plain is known as Bella Union, the surface is some 300 or more feet above sea level. In the valley of the Rio Grande, sections of what appear to be late Tertiary may be seen. On the coast near Santa Ana, similar sections may be found. On the southwest flanks of Cerro Yunga, the same sediments are exposed. In the interior, on the inner edge of the Pampa de Yunga, is the so-called Vallé de Carbonaria, where a considerable thickness of clays and sands, presumably late Tertiary in age, may be seen.

To the south of the plains bordering the Valley of Yauca, the foothills once more form the present shore line. Nevertheless, in the mouth of the Valley of Atiquipa and again in the Chala may be found a triangular patch of what appear to be late Tertiary clays and sands; but beyond this point the foothills seem to present a solid front, until we reach the mouth of the Ocoña Valley. This, however does not prove to be the case. Should we enter the mouth of the Atico Valley and journey in the direction of Caraveli, we should find that the supposed foothills of west range of the Andes prove to be outliers, separated from the main range by much-dissected plains made up of Tertiary and post-Tertiary formations, and that these extend to the actual foothills of the Andes in the vicinity of Caraveli. These plains probably pass to the northwest as far as the valley of the Chaparra and represent the northwestern limit of the south division of the coastal plains. The inner edge of this plain is not less than 3,000 feet above sea level and has a width of twenty-five miles or more. The pre-Tertiary coastal ridge as far as Ocoña shows only its highest point at elevations exceeding the general level of the interior plain, while its shoreward flank has been nearly stripped of its post-Cretaceous covering. It is in sections on the Caraveli and tributaries to the Atico that we find for the first time that mud flows of no mean proportions enter into the formation of the coastal plain. In Quebrada Chinchin, we may see at least 300 feet of this flow exposed. Moreover, these flows extended far in the direction of the coastal ridge. From the region of the Atico section, we may trace the high plains to the southeast, being represented by the Pampas de Paca Alta, Bourbon, etc., to the valley of the Ocoña; then we find the continuation in Pampas de Cuno-cuno, Majas and Vitor, where we reach the valleys of Siguas and Vitor. The inner edges of these pampas stand at least 5,000 feet above sea level. They are very deeply cut by the main streams coming from the West

Range, in fact most of them have cut veritable canyons and, in many parts, are still continuing the process of incision. The inter-stream spaces are, as yet, barely scratched by tributaries to the master lines of drainage. The pampas thus far named are but high-lying plains, with their initial surfaces well preserved. They are veritable deserts.

To the southeast of the Vitor Valley we find the pampas of La Joya and Chachendo, the two being partly separated by outliers of the West Range, while nearer the coast and on the northwest side of the valley of the Tambo we find the pampas of Islay and Tambo.

Crossing the Tambo Valley, we meet the lower plains adjacent to the shore line and usually known as the La Punta Plains. Crossing the coastal ridge, however, we come upon a higher-lying plain of enormous dimensions and usually known under the name of Clemesi. It extends with little interruption to the valley of the Moquequa. It decreases very materially in elevation as we pass from the Tambo to the Moquequa Valley. On the Moquequa, the plains have a width of from twenty to twenty-five miles.

Of all the pampas so far mentioned in the southern coastal plain, the lava flows already mentioned form no inconsiderable part of the deposits making the Siguas-Vitor La Joya sections. Excellent sections may be seen on the Siguas and Vitor valleys. Here can be seen two distinct flows, as indicated by the inter-stratification with sediments. The maximum development of the flows seems to have taken place along a line or section from Arequipa to Quilca, the former town being located well within the west slope of the West Range of the Andes, and on the contact of the flow with older formations.

Just what may be the correct correlation of the sediments of these sections with those of the central and northern division of the coastal plain has not been determined with any degree of certainty; it is mistrusted, however, that they represent rather late phases of Tertiary deposition. It is important to note, as well, what an enormous amount of elevation has taken place, since their deposition, since we now find some of these at least 1,000 feet above sea level. There is no proof that the lava plains as a whole ever stood at sea level. The fact, however, that salt deposits are known to occur well up to the higher plains indicates a depression of such extent that a part at least of the mud-flow must have been near sea level.

Returning to our description of the areal extent of the southern division, we find that the Pampa de Clemisi has suffered but slight erosion. Near the inner edge of the Cadena de la Costa are some very fine salt deposits. The best sections are to be found in the slopes of the Moque-

PLATE XXIV

COASTAL CHAIN OF PERU

A view of the coastal chain as on its inner edge between the Valleys of the Tambo and Moquequa. The flat foreground represents the coastal plain. Large salt deposits occur in this section.

PLATE XXV

MOQUEQUA VALLEY

A view of the valley of Moquequa at the contact of the coastal plain with the foothills of the west slope. The coastal plain sediments show clearly in the foreground.

PLATE XXVI

SHORELINE AT MOLLENDO

A view of the shoreline at Mollendo showing pre-Tertiary rocks (gneissoid and dioritic rocks) of the coastal chain in the foreground covered in part by sands and clays of the coastal plain.

PLATE XXVII

MOQUEQUA (ILO) RIDGE

View of the Moquequa (the Ilo) near the coast where it has cut a deep gorge in the Coastal Ridge.

qua Valley and in the Cuesta de Mato de Caballo. Here is exposed a series of somewhat coarse deposits on top, followed by a thick series of clays and fine sands. Folding and faulting have taken place to a considerable degree.

The Pampa de Clemesi has an elevation near the Tambo Valley of some 4,000 feet on its inner edge, but it descends in the direction of Moquequa and Locumba. At the valley of Sama, which at present constitutes the dividing line between Chile and Peru, the elevation at the inner edge is not more than 800 to 1,000 feet. The same grouping of sediments may be seen on the Sama as in the Moquequa Valley.

As regards the character and distribution of the outliers,.a word must be added. The pre-Tertiary coastal chain is persistently present from the valley of Atico to the mouth of the valley of Sama. Near the valley of the Tambo, the edge of the foothills practically joins the Cadena de la Costa. It is for this reason that we have a number of small pampas separated by a collection of outliers. In the stretch of coast from Mollendo to Quilca and Camaná, the coastal ridge is most prominent in its topography and reaches a width of some kilometers. Their topographical strength, however, gradually fades away in the direction of Sama. To the south of this point, I am told, the ridge is replaced by a series of morros, of which the historic morro at Arica is a good example.

Original Tertiary Area.—At the present time we probably see but a small portion of the original area of deposition of Tertiary time. The Bay of Guayaquil is very shallow and may represent a slightly depressed part of the Zorritos-Tumbes plains. That Tertiary deposits extend some distance to sea in front of the Zorritos-Nigritos shore line is more than probable. This conclusion is borne out by the fact that, for many years past, mariners have repeatedly reported the occurrence of oil patches on the surface of the sea some miles out from the present shore line. Further, such reports are not confined to this part of the coastal shelf, for quite recently similar evidence has been noted in the region of the Lobos Islands, located in front of Pacasmayo. In fact, so marked was the evidence that parties of Lima have recently attempted to take up territory on the above-mentioned islands, with a view to developing a petroleum industry.

So far as is known to the writer, petroleum-bearing formations of the coast are confined to the Tertiary horizons. Even in the interior of Peru, in the region of Lake Titicaca, there is every reason to believe that the petroleum deposits of the Pusi section are likewise confined to the Tertiary.

Locus of Agriculture and its Dependency upon Physiographic Phenomena.—In these days, much is said about physiographic features as determinative factors in the location of human industries. A word concerning the distribution of agriculture on the coastal plain is worth while.

Mention has already been made of the differential elevation which the coastal plains of Peru have suffered. Where the elevation has reached its maximum, or where the plain has been aggraded to a much greater elevation, as by the addition of lava flows, the present streams coming from the flanks of the oldland (the west slope of the Andes) have cut out veritable canyons. Time enough has not yet elapsed to permit these streams to widen their floors to any appreciable extent. Here and there in some of the canyons, the stream has reached the underlying oldland and its rate of erosion has been retarded. Above this point, the stream has thus had some opportunity to do some side cutting and hence has widened its floor; only at these points do we see man availing himself of the agricultural opportunities offered him. In proportion as the elevation has been less so in a general way, we may say that transverse master streams have had a chance to make floor room for the use of man. Let us take a few examples to illustrate the principal stages and their physiographic bearing on the topic in hand. Probably the maximum elevation of the coastal plains of Peru was attained in the Mollendo-Arequipa, or Vitor, section. While formations entering into the structure of this section are in part sedimentary in origin, it is not assumed that the present elevation of its surface above sea level represents the actual uplift above that plane. It is very probable that this part of the plain has actually been aggraded by a lava flow, or flows, the present surface of which never stood at sea level, although the lower part of the earlier flows may have reached the edge of the Tertiary sea. At all events, the Chile-Vitor stream coming from the high plateaus to the interior have, within the limits of the coastal plain, succeeded in cutting a very deep canyon. Further, it has developed its widest floor near the contact of the inner edge of the plain with the pre-Tertiary oldland, or the foothills of the West Range of the Andes. For that reason we have Quercotilla, an agricultural community and a village, located at this point. Within the remainder of this valley to the sea, we do not find a single town until we reach the present shore line, where Quilca, a small village, is not placed on the valley floor, but to one side in a deep-water embayment of fiord-like character. This little village is here for the dispatch by water of agricultural products from the valleys of Camaná and Ocoña, neither of which possesses a safe port of entrance. Mention has also been made of the special case of

PLATE XXVIII

CHILE-VITOR CAÑON AND THE FOOTHILLS OF THE WEST RANGE OF THE ANDES

PLATE XXIX

CHILE VALLEY NEAR AREQUIPA

The floor of the Chile Valley in the region of Arequipa showing alfalfa fields. This is near the contact of the mud-flow with the edge of the foothills of the west slope.

Arequipa. Arequipa is some miles within the interior of the West Range of the Andes. It stands on the slope and near the edge of the lava flow, or flows, playing so important a role in the lithological content of the coastal plain to the southwest. To the rear of the city, and forming a most picturesque background, the majestic cones of Misti, Pichu-pichu and other volcanic ridges rear their heads to 19,000 feet or more above sea level, and 9,000 to 10,000 feet above the light-colored lava plains of the Arequipa campo. The Chile River coming from the high plateau to the interior passes between two of these cones, where it has cut a most picturesque canyon, pushing its way across a part of the mud flow until it reaches the contact with pre-Tertiary formations of the foothills. The important fact to note here is that where the Chile succeeded in making a valley-floor, namely, at the moment it reached the contact referred to above, there was located the city of Arequipa. Here we find agricultural pursuits well developed. In all of the southern part of Peru there is no prettier bit of landscape to be found than the campo of Arequipa. It is the Switzerland of Peru. That is to say, physiographic features were the determinative factors in the location of this important trade center.

In the Valley of Majas, we again find that a valley-floor has been developed near the contact of the inner edge of the coastal plain with the edge of the foothills of the West Range. Here has developed a large grape culture and the manufacture of wine; but from this locality across the plain we find little chance for the farmer. Not until the Majas passes through a deep, narrow gorge cut in the coastal ridge, or cadena de la costa, do we find an additional opportunity for the development of agriculture. As soon as the Majas passes beyond the west slope of the ridge, it has greatly widened its valley, having cleaned away the sediments on the west flank and built for itself a broad, semi-triangular fluviatile plain, which has pushed seaward sufficiently to be a menace to the mariner. On this plain, we find the agricultural town of Camaná located and a campo alive with agricultural activities.

The plain on which stands the city of Lima and its suburban towns is but a repetition of the same physiographic sequences, the difference being that the Lima plain was built at the edge of the cordillera or foothills proper of the West Range of the Andes, while the latter developed on the seaward edge of an outlier of the same physiographic province.

In the Valley of Pacasmayo, we find that the river cut its way to the sea and at the same time widened its floor throughout its entire course; as a consequence, no inconsiderable part of the entire floor from the edge of the foothills to the present coast line is under cultivation, or has been at various periods. The amount of cultivation is, in some cases, dependent upon the amount of available water. In the Pacasmayo case we find an additional feature worthy of mention. At the contact of the coastal plain with the foothills, the valley has not been deeply incised. On both sides of the valley are extensive plains, composed largely of the waste from the edge of the foothills, plus the original surface of the coastal plain. So near are these plains to the level of the river, but a short distance within the foothills, that water has been diverted from its legitimate place on the valley-floor to irrigate large stretches of plain on either side of the valley. Success in this attempt has been foiled, in part, by the lack of water for the extent of territory taken up on the one hand and the strong tendency to salinity of large tracts of the plains on the other.

It is only where the coastal plain has undergone the minimum amount of elevation that we find the last distinct stage to be described. This is fairly well illustrated by the Etén-Lambayeque-Motupe plains, where we have a group of small streams coming from the interior to a slightly elevated plain. Only along the inner contact of the coastal plain with the foothills have these streams slightly incised themselves, but as they extended outward and over the plain they actually spread their waste over large areas. Under such physiographical relations, we have the conditions for the development of the most important rice industry in the entire Republic of Peru. The rice fields occupy the fluviatilly aggraded portions and such adjacent parts of the original plain as may be reached by the amount of water available. The growth of sugar cane has also become an important industry. Where the main streams have formed a well-defined valley-floor, the predominant culture is of maize, alfalfa and the staple vegetable products for the markets of the principal towns.

In the valley of the Piura, we find a slightly incised valley, the floor of which is occupied by cotton culture, as the foremost industry, throughout its upper stretches. Notable lack of water has limited the territory under cultivation. Piura and Catacaos are located at these points. Again we find this portion of the valley-floor near the inner edge of the coastal plain. The lower portion of the Piura Valley has spread itself over the plain. Not enough water reaches this part to assure crops. The town of Sechura is located near the mouth of this sand-laden water-way. The people here can maintain themselves only in part by agricultural work. Not a small part of the inhabitants is engaged in transportation, fishing and salt-mining.

FIG. 1

FIG. 2

PLATE XXX

WEST CORDILLERA NEAR CERRO DE PASCO

FIG. 1.—Limestone summits in the West Cordillera as seen in the Oyon-Cerro de Pasco Section.

WEST CORDILLERA NEAR UTOTO

FIG. 2.—The West Cordillera in the region of Utoto, showing limestones on the left and volcanics on the right. Ore bodies exist near the contact.

WEST SLOPE AND WEST RANGE OF THE ANDES

We now come to the geographical province which I have designated as the West Slope and West Range or Cordillera of the Andes. So far as I am aware, no one has attempted to outline the physiographic history of this section, nor is it my intention to try to solve this problem in all its details; nevertheless, I wish to present a few of the larger physiographic features and their variations as observed in various sections on the West Slope, with the hope at least that these may lead in the direction of a correct and final analysis.

As a basis upon which to formulate our views, I shall describe what to me appear to be two fairly typical cross sections of the West Slope in central and southern Peru. These I shall designate as the Huacho-Oyon section and the Ocoña-Cora Puno section.

Huacho-Oyon Section.—The town of Huacho lies about sixty miles to the northwest of Callao, on the coast, in the valley of the Huari. You may ascend from Huacho up to the Huari Valley and its important branches to Oyon. Oyon stands at the base of the more prominent peaks of the West Range, hence the choice of the two names to locate the section to be described. The distance from Huacho to the east side of the West Range is approximately 35 leagues, 175 kilometers, or 105 miles. Beginning at Huacho, we find that the valley of the Huari has a broad flat floor at the present shore line. It extends inland some eighteen to twenty miles. It is the seat of important agricultural industries. At the apex of the Huari floor we find the river running in a deeply incised valley. Its tributaries have likewise cut canyon-like side valleys. On either side of the Huari Valley, at the coast line, we find that the foothills of the West Range come practically to the present coast line. Should we ascend to a point in the foothills from which a long-distance view of the upland surface may be clearly seen, we shall at once note a moderately even but highly inclined surface descending in the direction of the sea and ascending in the direction of the culminating points of the West Range. As we pass in the direction of the snow-capped prominences to the northeast, the inclined surface gives way to prominences standing out in clear relief above the upland surface. These finally culminate in the peaks of the West Range of the Andes. In the Lima-Oroya section, the above physiographic features can be discerned, but they are by no means so clearly defined. If we look into the details of topographic expression on the West Slope, we find that it has been most minutely cut by steep, narrow valleys leading to the master transverse lines of drainage from the interior. The formations entering into the structure of the West Slope are

Cretaceous or older sediments and volcanics. The latest formations, at least, are not younger than Cretaceous. We also have good reason to believe that the oldest formations entering into the coastal plain are not older than early Tertiary. It therefore follows that the topography of the West Slope must have been developed in post-Cretaceous time, or more accurately, between the period of uplift of the Cretaceous sediments and their associated volcanics and that of the initiation of Tertiary sedimentation. It was during this interval that the present topographic detail in its large phases as now expressed on the West Slope was delineated.

From the data at hand, the successive steps seem to have been as follows: At the close of Cretaceous sedimentation and volcanic activity the West Range of the Andes was elevated; the west side of the uplifted section was subsequently worn down to a poorly graded surface, at least in the Huacho-Oyon section; this stage was followed by a strong uplift and subsequent deep dissection, or erosion. This was followed, in turn, by the depression of at least the shoreward edge of the post-Cretaceous land-surface and the initiation of Tertiary deposition. In other words, Tertiary deposition took place on the partly drowned edge of the West Slope.

Ocoña-Cora Puno Section.—This section has been chosen for the reason that the observed facts show considerable variation from the one already described. The town of Ocoña is situated on the coast some seventy miles to the northwest of Mollendo. The point known as Cora Puno is located near the western edge of the West Range. It is one of the highest collection of volcanic peaks on the west of the Cordillera. Starting at Ocoña, we shall run our section across the immense plain or desert of Cuno cuno to the valley of the Chorunga, thence up the Andaray cuesta to Cora Puno and the West Range.

The formational and topographical facts are roughly shown in the accompanying section. At Ocoña, we have the pre-Tertiary coastal ridge facing the present shore line. On its west slope may be seen patches of Tertiary and post-Tertiary still inviting the attack of the Pacific waves. Passing inland, however, we find that, as we reach the level of the pampas, pre-Tertiary formations may be seen at many places sticking through the thin sheet of late sediments at elevations of 3,000 or more feet above sea level. As we pass towards the north we soon realize the fact that the surface of the Cuno cuno plain has once been covered in part at least by a sheet of mud-like lava. Only in the deeper side-valleys leading to the Ocoña canyon can we see the sediments as recognized near the coast. This light-colored sheet now persists until we reach the steep slope that passes into the Chorunga Valley. Here the Chorunga as well

Fig. 1

Fig. 2

PLATE XXXI

INNER EDGE OF THE PAMPA CUNO CUNO

Fig. 1.—A view of the inner edge (inface) of the Pampa Cuno cuno (coastal plain) as seen from the stripped upland of the west slope in the region of the Valley of the Choringa-Ocoña-Cora Puno Section.

CUESTA DE IQUIPI, NEAR VIEW

Fig. 2.—A closer view of Cuesta de Iquipi, or inface of the coastal plain as seen from opposite the Rio Grande Valley-Ocoña-Cora Puno Section.

as the Rio Grande and the Ocoña have succeeded in cutting through, not only the soft lava referred to above and the underlying sediments, but also have deeply incised themselves in the underlying pre-Tertiary formations of the partly buried foothills, or, more accurately stated, have cut through the coastal plain formations until in the Valley of Chorunga the line of erosion adjusted itself to a pre-Tertiary topography. That is to say, the Chorunga simply cleaned out the mass of sediments and sheet of lava which had been dumped into it during Tertiary time. This is evidenced by the patches of lava that still hang in the little recesses on the southwest slope at various points between the Rio Grande and the Andaray cuesta.

Ascending the Andaray cuesta, we go but a short distance up the slope before we again see remnants of the familiar lava sheet of the Cunocuno plain, still nestling on the slopes and in the protected valleys of the uncovered foothills leading up to the base of the Cora Puno domes. At Andaray and Yanaquiqua, we can see the same facts well illustrated. Andaray is located in a depression in the foothills, the bottom of which is still in part occupied by the light-colored lava. From Andaray, we pass up another steep slope, or series of slopes, composed in part of pre-Tertiary rocks, only to find that we are again on a somewhat dissected plain which extends away to the east in the direction of Chuquibamba and north in the direction of the picturesque Cora Puno. Lithologically, this is the same type of rock as that which we have already seen in the Chorunga Valley, the Andaray cuesta and the inner edge of the coastal plain. It is my belief that the plains at the base of Cora Puno group of domes are but parts of the same lava plain that we have already recognized in a portion of the Cuno cuno desert. Continuing our journey to the north, we come to the somewhat rugged, jagged edge of a still higher plain that is made

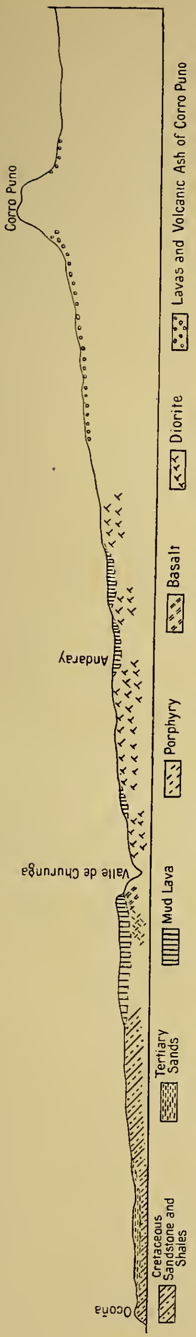


FIG. 1.—Geological section from Ocoña to Corro Puno.

up of a vesicular scoriaceous black to gray lava. Standing on top of this is the picturesque group of Cora Puno domes, four in number. So far as personal examination was made, it was found that lower slopes of the domes were composed of a succession of ropy lava flows alternating with volcanic ash and cinder-like layers. Nestling in the valleys between the domes are fine glaciers. On the southwest side of the group, there may be seen a very fine icefall, with an exposed edge of not less than 200 feet.

At the time of visiting this locality, the domes were well covered with snow. So symmetrical and smooth did the domes appear, even to their summits, that the writer felt that with a specially constructed snowshoe an ascent might be made without serious difficulty.

The base of Cora Puno is about 14,000 feet above sea level. The domes are not less than 20,000, and one of them may reach the 21,000-foot mark.

Before interpreting the physiographic value of this section, let us look at another running from Ocoña to Caraveli. In this case we start at the coast with the nearly buried coastal ridge facing the Pacific. Going inland we pass over a succession of plains arranged in bench-like order. The natives have applied names to each of these. Near the coastal ridge, the plain is composed of sedimentary formations, but we do not go far to the interior before we recognize the fact that the light-colored lavas form the only visible lithological unit exposed in the deeper valleys of the plain. Should we go from Caraveli to Atico, we will again cross the lava plains, but in the lower part of the Atico group of valleys we will see that sands and conglomerates become important members of the coastal plain deposits. Furthermore, after we leave the outliers at the shore line of Ocoña, we do not come again in contact with the pre-Tertiary oldland until we pass through the Quebrada de Chin Chin to the Caraveli Valley. From Caraveli inland, the foothills ascend rapidly to the elevation of the basal plain of Cora Puno. Above this elevation tower, here and there, occasional peaks, most of which are quite different in topography from those of Cora Puno. They represent elaborate groupings of spires and pinnacles, at places so steep that snow seems unable to cling to their sides. Should any one of the enthusiastic mountain climbers who have recently achieved noted success in mountain climbing in central Peru care to investigate this region, he will be sure to find opportunities for testing his skill, of which he had never dreamed.

We see, then, in the first-mentioned case, the oldland, or a portion of the West Slope, has scarcely been buried beneath the Tertiary deposits and no small part of these is composed of mud flows capping the entire series. In the section to the west, however, we have seen that sedimenta-

PLATE XXXII

DOMES OF CORA PUNO

Fig. 1.—A view of the domes of Cora Puno.

CERRO SOLIMANA

Fig. 2.—A view of Cerro Solimana, a neighbor of Cora Puno. Note the differences in topographic form.

FIG. 1

FIG. 2

tion was predominant near the edge of the coastal chain and also in the lower part of the Atico Valley; but it should be added, in the latter case, that much of the upper part of the sediments may be post-Tertiary and associated with glacial waste. At least, in the Atico-Caraveli section, we see nothing of the oldland upon which these late sediments rest, until we approach the vicinity of Caraveli. From these sections, it would appear that the West Slope in this locality was never reduced, or worn down to a grade, whereby even an approach to an even sky-line was attained, as noted in our northern section, but was occupied by valleys and hills of large dimensions when Tertiary sedimentation and volcanic eruption became prominent phenomena. The pre-Tertiary foothills were only partly buried in sediments, but later they became almost obliterated by the accumulation of mud flows of great thickness and areal extent.

It is thus evident that the physiographic history of the West Slope is by no means simple. To get a clear insight into the possible variations and succession of events, sections should be studied in every department and province facing the Pacific coast.

In the main, however, I believe that we have noted the chief succession of events and the principal factors involved, namely:

(1) The development of an oldland surface upon Cretaceous and probably older formations and corresponding to the western slope of the West Cordillera.

(2) Its elevation and deep incision of valleys.

(3) The depression of the shoreward portion, which, during Tertiary time, was in part at least covered with Tertiary deposits, and portions of which now form the present coastal plains.

(4) The differential elevation of the coastal plain deposits and the extension of the drainage of the oldland to the present coast line. In all probability, no small part of the original area of Tertiary deposition may now be beneath sea level.

HIGHLAND PLATEAU OR INTERCORDILLERAN BELT

To the belt of country lying between the eastern and western ranges of the Andes, I have applied the terms Highland Plateau or Intercordilleran Belt. These terms are used in the broader sense and for the need of better ones. Although presenting a complex geologic history, it can be traced from central and northern Bolivia throughout the entire length of the Peruvian Republic and into Equador; its width, in general, varying from 100 to 200 kilometers.

In the south of Peru, it is in part occupied by the most picturesque inland body of water of which the South American continent can boast, the well-known Lake Titicaca. To the southwest of Lake Titicaca, we have a somewhat dissected area drained by the Rivers Blanco, Cancomarca and Maure. To the southeast, we find the extension of the broad plains leading to La Paz, Bolivia. To the northeast, the Titicaca plains soon melt away in the foothills of the East Cordillera, whose long unbroken front, as seen from Lake Titicaca, presents a spectacle of mountain scenery that is not duplicated until we reach central Peru. To the northwest, we find that the Titicaca plains give place quite rapidly to a highly dissected belt. The streams coming to the Titicaca basin from the northwest are short, and their floors are very much aggraded, representing arm-like extensions of the enormous pampas to the north of the lake. As soon as we pass over the drainage divide at La Raya, we drop into an area that has been deeply cut by the drainage system of the Apurimac. It represents the headwaters of the Tambo and Ucayali, the latter joining the Marañon, and it, in turn, emptying into the Amazon. Of this stretch of country, the writer is personally acquainted with the Cuzco section, or rather, the belt etxending from La Paz, Bolivia, to a cross section through Cuzco.

Let us search for a locality where we can get a clear sweeping view, both to the northeast and southwest. To do this, we must ascend to the upland surface into which the Urubamba and Apurimac systems of drainage have deeply incised themselves. Various points of vantage may be found in the highlands overlooking the valley of the Urubamba between Cuzco and the Pueblo Urubamba, or from high points overlooking the valley of the Apurimac. Selecting a high point among the latter, and looking to the northeast, we will see, in the foreground, as it were, really two ranges looming up before us, and far above the level on which we are standing, one lying between the Apurimac and the Urubamba, and the other between the Urubamba and the head-waters of the Madre de Dios. While topographically these form parts of the East Cordillera, I am inclined to believe, from a geological point of view, that only the range lying northeast of the Urubamba-Villcanota valleys belongs in the East Cordillera proper. One could not wish for a more varied bit of mountain scenery than that from Sicuani to Cuzco. To the northeast, we have the pinnacle, spire and knob-like topography that characterizes a region of great volcanic activity. To the southwest, however, we have a very different expression, that which characterizes a belt occupied largely by sedimentary formations, here and there disturbed by local volcanic intrusions.

PLATE XXXIII

INTERCORDILLERA NEAR CUZCO, LOOKING EAST

Fig. 1.—A view of the sky-line of the intercordillera belt in the region of Cuzco, looking east.

INTERCORDILLERA NEAR CUZCO, LOOKING SOUTH

Fig. 2.—A view of the sky-line of the intercordillera belt in the region of Cuzco, looking south.

FIG. 1

FIG. 2

From the point of view selected, we see a billowy mass of ridges whose summits correspond roughly to the level of those on which we are standing. This view passes across the Intercordilleran Belt, while the former, in part, belongs to the East Cordillera. From a physiographic point of view, we thus have, first, the Intercordilleran Belt, a highly dissected plateau, longitudinally drained by the Apurimac and its branches heading against the east flank of the West Cordillera; second, the East Cordillera, behind which run the Urubamba and Villcanota systems, also in longitudinal position; but these finally succeed in cutting their way across the final range to join the Ucayali, which passes west of north through the Department of Loreto and drains for many miles the inner edge of the Amazonian plains. It is on this river that the important inland city of Iquitos is situated.

Cerro de Pasco Section.—Let us now examine the topographic characteristics to be observed in a cross section passing through the mining town of Cerro de Pasco and connecting with that which we have already described under the name of the Huacho-Oyon section. In this way, we can get a long-distance view of the principal features of these geographic provinces extending from the coast to the East Cordillera. As we have already stated, Oyon stands on the western slope of the West Range. Let us now go from Oyon to an advantageous point of view in the Uchucchacua section, where we may obtain a clear view both to the east and to the west. Such a point may be found near the main trail from Oyon to Cerro de Pasco and not far from the "pass," with an elevation between 16,000 and 17,000 feet above sea level. To the west and southwest will be seen the western slope of the West Cordillera, as already described. To the east, we will see, some 3,000 or 4,000 feet below us, a stretch of rolling undulating country extending to and beyond Cerro de Pasco. Occasional knobs and ridges may be seen at various points standing on the plain and serving as guides and mileposts to the explorer. From the same point of view, on a clear day, the East Range may be seen, away to the east and northeast of Cerro de Pasco. Here may be found the grandest and most magnificent group of ridges and peaks rearing their summits far above the line of permanent snow. There are peaks here that pass far above the 20,000-foot level. Into this Intercordilleran Belt the headwaters of the Huallaga have cut their way southward into the vicinity of Cerro de Pasco, having pushed through a part at least of the East Range. It is important to note here that the Huallaga did not succeed in cutting its way through the entire East Cordillera to join the Ucayali, but was forced to maintain a longitudinal position as far as Huanco. Then it broke through the East Cordillera to join the Marañon far to the north. It thus maintains a position approximately parallel to the Ucayali throughout a long distance.

The Cerro de Pasco plain is quite clear as far south as Oroyo. In this part of the plateau we again find a pretty sheet of water, but very much smaller than the inland Titicaca. From this body of water, known as Junin, the drainage, instead of going to the Huallaga, now goes to the southeast, the main line of drainage being the so-called Mantaro. From Oroya to Huancayo, the Mantaro has made a most picturesque valley, on the floor of which are located many prosperous agricultural communities. Ascending the highland in the region of Huancayo, we can see to the east the picturesque Cordillera de Marca Valley, really a part of the East Cordillera, while to the west may be noted the West Range presenting an almost unbroken front.

From Huancayo, the Mantaro continues its course to the region of Mayoc, where it breaks through the frontal East Range and deflects again to the northwest for some distance, but finally elbows its way across the last eastern barrier near Huaribamba and joins the Apurimac. We thus find here another illustration of a pattern of drainage which suggests an adjustment to structure, such as may be seen in many other regions the world over.

Relative to the section between Mayoc, or the first elbow of the Mantaro and the Cuzco-Abancay region, I may add, from data obtained from explorers, that it is apparent that it is a broad highland belt into which the east tributaries of the Apurimac have incised themselves until they have cut the entire section into a veritable labyrinth of canyons. In other words, it is simply a continuation of what we noted to the southeast of Cuzco.

Casma-Huaraz-Huacaybamba Section.—Let us now look at a section through the northern part of the Department of Ancachs beginning with Casma on the coast and ending at Llata on the Marañon. At Casma, and far to the north and south, the foothills of the west slope form the coast line. The main transverse valleys have been aggraded near the present shore line, but we do not go far to the interior before the flat floors are replaced by steep-sided V-shaped valleys. Here again we have the rapidly descending surface of the West Slope; to the interior, this culminates in the West Range, which in turn overlooks the valley of the Huaráz. The highest points of the range in this section do not exceed 15,000 feet. From an examination of the Raimondi map, it will be seen that it is well defined throughout a large part of the Department of Ancachs. Note the fact, however, that in the place of the broad plain, as found in the Cerro de Pasco section, occupying the belt between the East and the West Cordillera, we have a comparatively narrow valley running parallel with the West Range. It is drained by the River Huaráz, occupying a longitudinal position throughout some three provinces, and finally in the Province of Pallasca turning to the west to join the Santa, which empties into the Pacific.

Continuing our section to the east from Huaráz we find in the place of the deeply dissected intercordilleran plain another range of enormous proportions and running parallel with the one already described. It reaches elevations of more than 20,000 feet at various points. From its east slope, however, we now see the much-dissected Intercordilleran Belt extending to the valley of the Marañon, a distance of perhaps seventy miles. We thus have in this section two ranges on the west side of the Intercordilleran Belt, instead of one, as in other sections noted; further, instead of an intercordilleran lowland, as noted in the Cerro de Pasco section, we have a deeply dissected belt whose uppermost surface has a marked descent towards the valley of the Marañon. To the east of the Marañon, we again have a somewhat softened expression of a continuation of the East Cordillera.

Let us now consider the position of the Marañon drainage system. It heads to the south in the Department of Junin in a collection of lakes within the limits of the Intercordilleran Belt. Following the main line of drainage, we find that it, like many others, skirts the east edge of the intercordilleran highland for many miles to the north, and finally, in the Department of Amazonas, turns east to join the Amazon system, of which it is an important member. Note again the longitudinal position of the Marañon with reference to the geographical provinces as outlined.

To the east of the valley of the Marañon, the Raimondi maps show a fairly well developed range separating the drainage of the Huallaga from its western neighbor. Just what this range is, geologically, is unknown to the writer, but it is believed to correspond to the East Cordillera.

Piura-Huangabamba Section.—To the east of the Piura-Salitral River the long western slope is absent, and we encounter immediately the continuation of the West Range with a rather abrupt slope, though softened in its topographic expression, as compared with sections to the south. This is followed by the intercordilleran highland, already thoroughly cut to pieces by parts of two systems of drainage. The section of the Intercordilleran Belt between Huangabamba on the north and Chota on the south is drained by the rivers Huangabamba and Chotana. These become confluent in the river Chamaya, which empties into the Marañon. Note again the longitudinal position of the Huangabamba and Chotana rivers with reference to our geographical provinces, while the Chamaya is typically transverse in position.

In the north part of the Department of Piura, we have some unexpected topographic variations. By consulting the Raimondi map, it will be seen that the part corresponding to the West Range has projected a long spur to the southwest, known as Cerro da La Brea, or Amotape Mountain. It is composed of Cretaceous shales and dioritic intrusives. It is flanked on both sides by the coastal plain formations. Note also the arrangement of drainage between the spur and the headwaters of the Huangabamba. The rivers Chira and Catamayo represent the main line of transverse drainage, while its tributaries the Suipirá, Quiros and Macará represent the longitudinal drainage of the somewhat depressed section of the intercordilleran plain.

EAST RANGE AND EAST SLOPE

Concerning the East Cordillera, we have already seen in our various views that it forms a prominent range of enormous altitude at various points and maintains its identity throughout the entire length of the Peruvian Republic. Its highest altitudes exceed those of the West Range. The most picturesque views may be had from the region of Lake Titicaca, where, on a clear day, it may be seen passing north from Bolivian territory into Peru and presenting apparently an unbroken front, as far as the eye can reach, to the northeast. It maintains its identity throughout the departments of Puno and Cuzco, reaching enormous altitudes in the Department of Junin, where it is deeply cut into serrated forms. We then can follow it through the department of Huanuco and San Martin and finally into the Department of Amazonas, where it apparently separates into two ranges and continues as such into Ecuador. While no great elevations are attained in northern Peru, they assume again in central Ecuador their old-time grandeur.

Concerning the East Slope of the East Range, I regret very much that I had little opportunity to see enough of this geographic province to warrant personal description in any detail. Only in southern Peru have I penetrated the East Cordillera to a point where a far-reaching view of the foothills and, beyond these, the great stretch of rolling and undulating lowland, may be had. The foothills proper do not occupy a very wide belt. They quickly descend to an elevation of not more than 4,000 feet and probably less, where, from the long-distance view at least, one would judge we should encounter the inland edge of the great Amazonian plains. These occupy the east portion of the Department of Puno, a very large part of the Department of Cuzco and nine-tenths of the Department of Loreto. It is on these eastern slopes and the huge plains below that we find uncivilized tribes of Indians, or the native "salvaje."

Topographic Expression as Related to the Geology of the Peruvian Andes

PLAINS AND SECTIONS

Zorritos-Lambeyaque Plain.—The formations of this division of the coastal plain are, so far as known, Tertiary in age. They are entirely sedimentary and are composed in the main of clays and sands with occasional pebble and conglomerate beds. From a section prepared by me, between Fernandez and the shore line, something like 3,000 feet of sediments can be calculated. More than 2,000 feet have been penetrated by the drill in search of new petroleum-bearing horizons both in Zorritos and Lobitos. I wish here to emphasize the point that the only localities where a topographic expression resulting from uplift and subsequent erosion may be found are confined to the three localities, Zorritos, Lobitos and Nigritos, where petroleum in large quantities has been obtained. Each one of these places is located on the east limb of a somewhat broken or locally faulted anticline. The formations as seen in the Fernandez section are regarded as lower and middle Tertiary. In the Lobitos, it is believed that we have middle and upper Tertiary.

In the Paita section, reference has already been made to the occurrence of a series of sands and conglomerates resting unconformably upon a mass of red clays. These deposits contain some fossils, apparently the same as those living at the shore line to-day. They are now 250 to 300 feet above sea level. As we pass in the direction of Piura, we can see little mesa-like elevations. These were found to be composed of the red clays seen in the lower part of the Piata section. It is thus evident that the red-clay deposits were elevated and eroded before the deposition of the conglomerates referred to above; and, further, the erosion must have been largely confined to the outer half of the Paita section.

It is important to note another fact at this point. At a number of places in the Paita-Piura Pampa or Despoblado, as the natives are accustomed to call these plains, you cannot fail to see small areas strewn with shells, all of which appear to be specifically the same as those living on the present shore line. This would suggest that, in very late geological time, the Paita-Piura Plain was beneath sea level, and that it was subsequently elevated to its present position.

As we pass to the south, the despoblado has been barely scratched by the Piura River and the surface subsequently littered up with wind-blown sands. That is to say, topographically, the plain is so young that it yet has the same expression as when it emerged from sea level. This condition is maintained throughout the Desert of Sechura and the Despoblado de Olmos. From Chiclayo and Etén south, we have but a rim of the coastal plain left. It attains considerable proportions in the mouths of the valleys of Pacasmayo, Chicama and Santa Catalina. From a topographical point of view, we have here but a narrow expressionless plain, with its seaward edge rapidly retreating under the attack of the Pacific waves.

The two prominent points where topographic expression relieves the monotony of the plains are Cerro or Silla de Paita and Cerro de Yllesca. These are, in a word, half buried outliers of the foothills of the West Cordillera. Similar cerritas may be seen in the broad opening of the Pacasmayo Valley. All these were little islands in a Tertiary sea. They are composed of Cretaceous shales and sandstones which have undergone metamorphism under the effect of intrusives.

Chincha-Olmos Plain.—From Chincha to Pisco, we have the same monotonous plain. It is not until we reach Pisco that we find a little topographic relief and this time again associated with the uplift of a series of light gray to cream-colored clays. We need, however, only to go a little distance inland to see a continuation of the pampa in the direction of Ica. Should we follow the coast, we should find that a considerable area is occupied by the outliers of the foothills, but these are quite modest in topographic expression. These pre-Tertiary hills continue to the mouth of the river Ica and attain considerable width.

I wish to turn aside here for a moment to refer to the Peninsula of Paracas, a short distance south of Pisco, since its geology is somewhat unique. Some time ago, coal was found in the cliffs of the peninsula, and a company was formed to exploit the deposits. Examination of the waste brought out of some of the prospects revealed the occurrence of true Carboniferous plants. It is the only locality known to the writer where undoubed Carboniferous and coal-bearing measures occur. So far as my observation goes, the Peninsula of Paracas is by far the most ancient "morro" on the entire coast of Peru. It is my belief that the formations entering into the remainder of the coastal chain, or Cadena de la Costa, are, geologically, much younger.

Passing to the other side of the shore ridge of which Paracas is the northwestern extension, we find the lowland facing the actual foothills of the West Cordillera cut into by the Ica River. Here we are relieved to find another good section of the same light-colored clays as seen in the Pisco section. As soon as we reach the Pampa de Huayuri, we are again greeted by an enormous stretch of high plain, and its monotony is only relieved when we reach the modest canyon cut in it by the Rio Grande.

On the southeast side and close to the coast is the Cerro de Yungi, another pre-Tertiary outlier. From this point to the termination of the Chincha-Olmos section we see again just the young Tertiary plain slightly cut into by the rivers de Acari and Yuaca.

Ocoña-Moquequa Section.—In the southern section, which may be aptly termed the Ocoña-Moquequa section, we have a repetition of the same topographic expression and the same formations involved, with one additional feature, and that is the role played by the mud flows. As already indicated, they form a very large part of the formations entering into the coastal plains extending from the Valley of Caraveli to the Pampa de Clemisi. The special feature of the south section is the persistence and strong relief of the coastal chain. It extends practically throughout the entire length of the coast line. I have indicated that the formations entering into the structure of the Cadena de la Costa are the same as appear in the north. While this may be true in some parts, I am inclined to think that, in the south, other formations than those of the foothills of the cordillera so far noted may be found in the Cadena de la Costa.

Huacho-Cerro de Pasco Section.—I have already called attention to the occurrence of an evident west slope facing the Pacific Ocean and the coastal plains. It has a marked inclination towards the sea. It is thoroughly cut to pieces by a network of transverse valleys. It is only when you ascend the uppermost edges of any of these valleys that this feature becomes apparent. Nevertheless, above the general sky line of the slope, we can see many elevations.

The geology of the above section is as follows. Near the coast the formations are sandstones and shales into which have been intruded two types of volcanics. These are then followed by a broad band of crystallines, probably diorites and related types. These are, in turn, followed by shales and sandstones. Large coal deposits are to be found in this part of the section. The shales and sandstones extend to and beyond Oyon. In the vicinity of Ututo, the sandstones and shales are replaced by an enormous thickness of limestones. Into the limestones and the inner edge of the sandstone and shale formations, enormous volcanic masses of at least two kinds have been thrust. In this section at least, the volcanics form most of the crests of the West Cordillera. The sedimentaries, especially in close proximity with the volcanics, have been folded and crushed on a very large scale.

The eastern slope of the West Cordillera is remarkably well defined. Limestones are here turned up on edge, and adjacent to this horizon we find the volcanics. Each formation presents its own type of topography.

At some points along the eastern slope, the escarpment is of such a character as to suggest faulting on a very large scale.

Continuing across the Intercordilleran Belt, consisting of an undulating plain, some 3,000 to 4,000 feet below the summits of the West Cordillera, we find the formations involved in its structure to be sandstones, shales and limestones, through which, at various points, knobs of volcanic rock have pushed their way and now form a part, at least, of the principal relief of the Cerro de Pasco lowland. The town of Cerro de Pasco is built on the slope of one of these knobs. Here we find a mass of volcanic rock in contact with a large body of limestone. It is on or near the contact that the famous ore body is located. Going northward over the intercordilleran lowland to Goyllarisquisca we again encounter coal-bearing formations. Just what are the stratigraphical relations between these and the coal-bearing measures of Ututo and Cajatambo is not known. Beyond this point the writer has not penetrated the wilds of the East Cordillera. From data obtained from prospectors and engineers, I have reason to believe that the principal formations involved in its structure are very much older than any we have seen in the West Cordillera. Probably Devonian and Silurian and older terranes associated with a huge mass of intrusives make up the great part of the East Range. By way of comparison, I may add that the formations found in the Lima-Oroya section duplicate, in the main, the Huacho section, both in succession and kind. Oroya stands at the south end of the Cerro de Pasco lowland. Here we have the expected limestones and shales and associated intrusives noted to the north.

Ocoña-Cora Puno Section.—Starting at Ocoña, we meet first of all the outliers within the limits of the coastal plain, or the Cadena de la Costa. Ascending the shoreward escarpment, we pass over the ridge and on to the edge of the enormous pampa which we already know under the name of Cuno cuno and have recognized as an intergral part of the Coastal Plain province. Should we pass into the canyon of the Ocoña, we should see the Tertiary sediments resting unconformably upon a series of sandstones and shales. Inland along the line of our proposed section, the Tertiary sediments give way to the development of an enormous mud flow, which, on the inner edge, or escarpment overlooking the valleys of the Chorunga and Ocoña, is not far from 1,000 feet in thickness. In the canyon of the Ocoña, in the region of Piuca, the pre-Tertiary sediments recognized nearer the coast have been largely replaced by various types of volcanics. There are at least three types to be found in the Ocoña and Chorunga valleys, namely, a dioritic, a trachytic and a basaltic type. Their succession of volcanic activity was probably in the order named. From the valley of Chorunga to Andaray, the dioritic formations constitute the principal formation. Ascending the highland above Andaray, we again find a broad plain extending away to the southeast in the direction of Chuquibamba. The plain is composed of the same sort of mud flow as we have seen on the inner escarpment of the Coastal Plain overlooking the Chorunga Valley. Through this protrude various knobs of diorite, the same horizon as we saw in the trail from Chorunga to Andaray. Into this plain the west tributary of the Majas River has cut a deep valley not only through the mud flow, but well into the underlying crystallines. On this floor rests the city of Chuquibamba.

Continuing our course to the north and northeast, we come finally to the edge of the lava flows forming a veritable platform on which were built the four confluent domes of the Cora Puno composed of lava, ash and scoria. A very large part of their slopes is above permanent snow line. These domes undoubtedly surpass 20,000 feet in altitude. From the northeast slope of Cora Puno we have before us a gently ascending plain, with cerros appearing here and there above the general sky line. Among these are the majestic Solamana, Leon Wachang and others with unpronounceable Indian names. And here let me say, if any enthusiastic mountain climber wishes to test his real ability, he should not miss trying the spires of Solamana. The plains between the peaks are, in part, at least, made up of a light-colored mud flow, lithologically the same as that seen on the other side of Cora Puno and the inner edge of the Coastal Plain or the Iquipi cuesta. Occasional small knobs of limestone protrude through this sheet. Also, where some of the streams have cut to any great depth, we sometimes find limestone exposures. That is to say, the light-colored lavas, the dark basal lava platform and the superimposed cones of Cora Puno, probably rest upon a floor of limestone on the northeast and dioritic crystallines on the southwest of Cora Puno. Such of the smaller spire-like hills as were examined were found to be volcanic.

In a word, then, comparing our sections, we shall find that we have a similar succession and order, with the exception that in the Huacho-Oyon case the Coastal Plain is absent. Physiographically, Cora Puno and the series of snow-covered domes to the southeast and northwest are situated well up the West Slope and not far from the West Cordillera. The important mining camp, Caylloma, is located on the east slope of the West Cordillera, into which the headwaters of the Apurimac are now cutting their way.

To the northeast from Caylloma to the Cuzco region we have the broadened Intercordilleran Belt, literally cut to pieces by the labyrinth of valleys occupied by the various tributaries of Apurimac and the Villcanote.

To the southwest from Cora Puno, we have the West Slope extending to the edge of the Coastal Plain, then follows the Coastal Plain to the Cadena de la Costa, the latter now bordering the present shore line.

If time would permit, a section passing from Mollendo through Arequipa to Puno could be shown to duplicate, in the larger phenomena, the facts already brought out in the Ocoña-Cora Puno section. I wish, however, to say just a word concerning the Titicaca region. The lake occupies a portion only of the Intercordilleran Belt. Within this basin, Tertiary sediments have been deposited. There is reason to believe that the Titicaca basin represents an area the depression of which was associated with down-faulting on a large scale. It probably extended from the north end of the Tertiary Titicaca well down to La Paz. Further, the Tertiary deposits rest upon limestones and shales. We are probably warranted in correlating the latter with the limestones and shales of the Cerro de Pasco lowland. To the west of the lake, we have the shales and limestones extending to the divide of Cerros de Toledo, where we again come in contact with volcanic intrusives, the true core of the West Cordillera. The belt of limestones and shales on the east slope of the West Cordillera has been traced to the Cuzco section. It physiographically belongs to the Intercordilleran Belt.

The section of Forbes brings to light the same physiographic features, the Coastal Plain, the West Slope and West Cordillera, followed by the Intercordilleran Belt and finally the East Cordillera.

Notes on Early Mining in Peru

To attempt to discuss the mineral resources of Peru in detail is not my intention at this time. I wish, however, to say one word relative to the early history of mining, its initiation by the Incas, its subsequent development during the period of Spanish rule, and finally to present a brief geographical and geological correlation and distribution throughout the West Cordillera and the Intercordilleran Belt.

While the Incas as a race were decidedly agricultural and pastoral in their vocations, they were, nevertheless, not ignorant of the use of the precious metals. This is proved by the occurrence of gold and silver vessels discovered in their notable monuments, known under the name of "huacos." The huacos are large quadrangular and pyramidal earthworks. They were probably used in connection with religious rites and ceremonies. While these constructions, or monuments, may be counted by the score near the coast, and usually are located on the floor of the broader valleys near a locality affording protection, the best preserved examples seen by the writer are to be found in the Valley of Santa Catalina (Salaverry). Very fine huacos may also be seen near Lima and within a day's ride from the Capital. Quite recently a pair of vases, each apparently beaten out of a solid piece of gold, was found in a huaco near Lima. From the Valley of Nasca, I have seen a large collection of gold bands, undoubtedly used as wristlets and as ornaments for the head. All these were discovered in the interior of a huaco. Hence all must have been of Inca manufacture, and from the crude metal obtained from its original source by these people.

With the invasion of Pizarro and his followers, and the subsequent establishment of Spanish rule over the Inca people, we have to note the introduction of a new regime. The invaders were primarily interested in the discovery and accumulation of the precious metals. On the other hand, the native was agricultural and pastoral in habit. As soon as the Spaniard had gained a knowledge of the gold-bearing possibilities of their newly acquired territory the labor problem became an important one. There could be but one outcome or solution on the part of the invaders. The natives were thus pressed into mining services and driven away from their chosen vocations. For a period of something like three centuries the native remained in a state of servitude to the Spanish rulers and people. If we can put any credence in various sources of information concerning the suffering of this inoffensive race, it seems most remarkable that they did not revolt and make at least one heroic effort to free themselves from the servitude into which they had fallen. It was during the period of the Viceroys that the gold-bearing resources of Peru became legend. That Peru was rich in the yellow metal was evident to the invader Pizarro upon his first survey of Cajamarca. Here he discovered and took charge of gold and silver to the amount of some three millions of soles in actual value.

To speak in general terms of the mining activities under Spanish rule, we may conveniently group the localities of maximum activity in the following manner:

(1) Cajamarca-Pataz Section. In this region, old Spanish prospects may be counted by the score in numerous valleys.

(2) Huaraz-Cajatambo-Cerro de Pasco Section. While the old Spanish workings are not yet known to be as numerous in this section, it is nevertheless certain that large amounts of both gold and silver were obtained, especially in the region of Cerro de Pasco.

(3) Cotahuasi-Andaray Section. In this section and as far west as the valley of the Chala, there are many abandoned prospects. In Andaray and the Cotahuasi vicinities, as well as in the Cerro de Pasco region, much work has been done since the establishment of the republic.

(4) Cuzco-Cotabamba Region. The region of Cotacamba and adjacent valleys was the scene of great mining activity in the early Spanish days. Many of these prospects have likewise been worked in late times.

(5) Poti-Sandia Section (East Cordillera). This is known to contain not only a large area of mineralized territory—gold-bearing quartz veins—but also an abundance of placer on the eastern slope of the East Cordillera.

(6) Huanaco Section (East Cordillera).

Just a word as to the distribution of the principal mining localities and their relation to the geology of the Cordillera. After seeing a large number of ore-bearing sections in the south, center and north of Peru, the relation and association of zones of maximum mineralization with certain formations becomes very clear indeed. Let us return for a moment to our Huacho-Cerro de Pasco section. Near the coast, there are a few intrusives which have pushed their way through the sandstones and shales. Apparently associated with these volcanics are gold-bearing veins which have been prospected from time to time. Nothing of very great value, however has been found here. The Spanish prospector did not find this little crop of veins very attractive. He was not slow to hunt more pleasing ground further to the interior.

It is not until we pass to the zone of the West Cordillera, where there are enormous intrusive bodies bordered by limestones and shales, that we find ore-bodies of large dimensions. On the west side of the Cordillera, we have a group of silver-copper-gold veins, some of which can be traced for more than a kilometer, with widths approaching 20 meters. Should we pass over the divide to the East Slope, from which we see the Cerro de Pasco lowland, we will find both on the slope and in the valleys leading to the crests of the Cordillera another group of veins that are undoubtedly associated with the east contact of the intrusives with the limestones and shales.

Throughout this region may be seen many old plants (arrastres) and the still more ancient quimbolete, where the ores were treated for the recovery of gold and silver. The amount of visible tailings show to what extent the early prospectors worked. Since the foundation of the republic, the native has likewise continued to work in this region, but, of course, in the old-fashioned way. It is not at all uncommon to find Indians in possession of solid silver utensils hammered out of a single piece of silver. Should you visit the plazas of any of the villages in these sections, you would find the silversmith present with his little collection of silver utensils and ornaments of various kinds. Most of the metal he obtains from miners of the same locality.

Passing over the lowland of Cerro de Pasco, we come to the noted deposit of copper-silver ore now in part the property of the Cerro de Pasco Mining Company. The ore-body appears to be on or near the contact of eruptives with a thick series of limestones. According to late statistics, the amount of silver taken out of the surface portion of the Cerro de Pasco deposit between the time of its discovery (1630) and the end of the nineteenth century amounts to some 450,000,000 ounces.

If we should return to the coast from Cerro de Pasco via the Cerro de Pasco Railway to Oroya, and thence via the Central Line to Lima and Callao, we should pass through other mining localities such as Rio Blanca and Morococha. Here again the respective ore-bodies are closely associated with contact phenomena such as have already been described. In the region of Matacana, a repetition of the same sort of occurrence may be seen. In the region of Lima, there are copper-bearing ores associated with eruptives in contact with limestones and shales. That is to say, the occurrences of ores in each section can be correlated both geographically and geologically.

Let us look for a moment at a south section across the Cordillera, say from Mollendo to Puno and the east. At Mollendo, we find that outliers of the Cordillera, or Cadena de la Costa, are composed in part of gneissic and granitoid masses, which are probably intrusive in sandstones and shales. Within the gneissic zones occur small copper deposits. While an attempt has been made to develop some of these, they have never reached the productive stage. Passing into the edge of the foothills in the region of Carabaya, just below Arequipa, we again find a band of crystallines bordered on each side by sandstones and shales. Prospecting on a small scale has brought to light small bodies of copper-silver ore, mostly located in the crystallines, while the sandstones and shales are reported to carry coal beds. It is not until we reach Lagunillas that we again come to a region containing ore deposits. Here are silver-gold-copper ores in a belt extending from Santa Lucia to Marivillas. This is to be correlated with the Caylloma silver occurrence already referred to. Here, as noted in other sections, we have eruptives associated with limestones and shales. These are probably to be correlated with the Morrococha Belt on the Lima section.

In the Titicaca basin to the south of Puno, ore deposits carrying silver and lead have been prospected. I have not seen these, but I am informed that the formations involved are the expected limestones associated with eruptives. Geographically this should be correlated with the Cerro de Pasco occurrence, as it lies in the Intercordilleran Belt and possesses the same lithological relationships.

Within the Titicaca basin, we have an additional occurrence which so far is not known to occur anywhere in the northwest extension of the Intercordilleran Belt. In this basin, there is a considerable series of sediments deposited upon limestones which are regarded as Cretaceous. The former are probably Tertiary. They contain petroleum, but development work has not been carried far enough to determine the areal extent of the oil sands. The only work of any moment has been done by the Titicaca Oil Company, backed by California people. Work has been suspended for the present.

The gold-bearing veins of Poti as well as those of the Santo Domingo region to the east from Tiripata are associated with the eruptives and older sedimentaries of the East Cordillera.

It is also known that the region of Huanaco, to the north of Cerro de Pasco, is highly mineralized. From data at hand it would seem that the geological associations are similar to those of Santo Domingo.

In the region of Huaraz and Recuay (valley of the Huaraz) there exists another mineralized belt containing silver, copper and gold ores, as well as lead ores. It is quite undeveloped. These are associated with intrusives of the West Cordillera.

Iron, copper and silver ores also occur in the West Cordillera, to the northeast of Piura. They are associated with dioritic intrusions and bosses in the midst of a heavy series of shales and sandstones.

RÉSUMÉ

In the Andes of Peru, we can easily recognize a series of parallel and well-defined physiographic provinces, which in the larger sense are definitely related to the geological development of the Andean Range as a whole.

Whatever has been the succession of physiographic changes in the development of the Andes as a unit, there has evidently taken place, at least on broad lines, a marked adjustment of drainage to structure, thus affording a longitudinal and transverse arrangement, or pattern, such as may be easily recognized in many other continental mountain systems.

A comparison of observed and recorded facts with reference to the occurrence of ore-bodies in Peru proves that they are generally associated with contact phenomena.

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NOTES ON THE STRUCTURE AND GLACIATION OF OVERLOOK MOUNTAIN

BY

Neil E. Stevens

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NOTES ON THE STRUCTURE AND GLACIATION OF OVERLOOK MOUNTAIN

BY NEIL E. STEVENS[1]

(Read by title before the Academy 6 May, 1912)

CONTENTS

INTRODUCTION

Overlook Mountain is the southern terminus of the great central mountain chain which forms the backbone of the whole Catskill system. On the east, the mountain rises precipitously above the low ground of the Hudson Valley, the land at the base of the steep incline on this side being only about six hundred feet above sea level. This commanding position gave Overlook for many years the reputation of being the highest peak in the Catskills, although it is actually more than a thousand feet lower than Slide Mountain (Slide Mt. 4204 ft.; Overlook Mt. 3150 ft.). The position of Overlook in the Catskill system makes it of particular interest; and the present paper, though it by no means contains a complete account of the geology of the mountain, is offered in the hope that the notes contained therein may be of service to future investigators and may, perhaps, stimulate an interest in the geology of this region. The writer wishes to acknowledge his indebtedness to Professor H. E. Gregory of Yale University for generous criticism and suggestions.

The summit of the mountain (Fig. 1) forms a triangle, from the apexes of which project three main ridges with smaller ridges between. The principal ridge stretches southwest for a distance of about four miles and ends in a series of three lower peaks, separated from the main peak by the Meads gap. The southern ridge is short and slopes rather sharply to the level ground of the valley. The northeastern ridge, on the other hand, is short and high, merging into the Plattekill Mountain

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[1] Introduced by James F. Kemp.

at an elevation of about 2500 feet. Aside from this narrow ridge, Overlook is separated from the mountains to the north by the valley of the Saw Kill.

STRUCTURE

Unlike most mountains, the Catskills consist of a succession of piled up, nearly horizontal strata, showing that they are really but the remains of a great interior plateau now greatly eroded and dissected by water.[2]

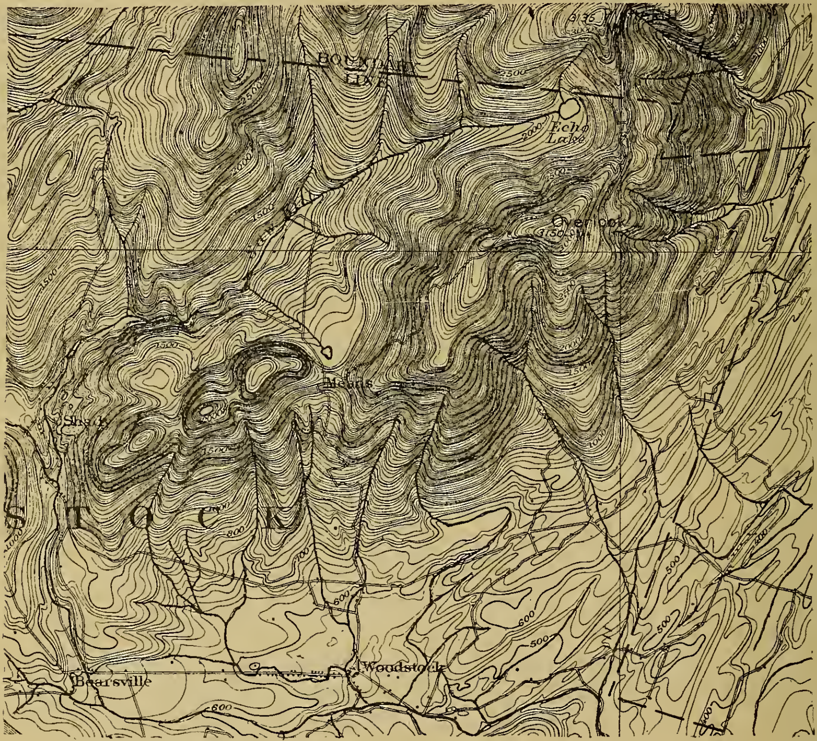

FIG. 1.—*Overlook Mountain and adjacent territory. A portion of Kaaterskill Quadrangle, New York*

U. S. G. S. Topographic Sheet. Reduced. Scale: 1/83332

Except for a layer of hard conglomerate which caps many of the higher peaks, the mountains consist almost entirely of alternate layers of soft red shale and harder sandstone. The sandstone is sometimes thinly laminated and frequently cross-bedded; often however it shows a very even

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[2] RALPH STOCKMAN TARR: The physical Geography of N. Y. State. New York, 1902, p. 41.

texture and is practically free from evidence of fine stratification. This latter variety of sandstone, generally designated as gray or blue flagstone, is extensively quarried for paving stone.

This alternation of soft, easily eroded, shales with the more resistant sandstone gives rise to the abrupt ledges, flat mountain tops and "terraced" sides so characteristic of the Catskills. Wherever a layer of shale has been exposed, the surface has been quickly eroded down to the next layer of sandstone. Nowhere are these features better shown than on Overlook Mountain. Note in Fig. 1 the plateau-like tops of the lower peaks and the terraces of the southern ridges.

Fig. 2 shows a section through the two lower peaks, between the Mead's Gap and the Bear Clove. This section extends from where the strata first appear above the glacial soil of the Woodstock valley, altitude 660 feet, to their summits, altitude 2100 feet. It is altogether probable that some of the strata, represented here as of uniform thickness, are really somewhat lense-shaped. This however could not be determined owing to the prevalence of glacial deposits. As will be seen from the figure, the cap of these peaks consists of nearly 600 feet of sandstone. The upper portion of this cap is hard and rather coarse, but the stone becomes softer and more finely lamimnated below. The lower layers of sandstone are characterized by a cross-bedded structure and contain numerous streaks of red shale too thin to indicate in the section. Besides the layers of sandstone and red shale there are, as indicated by the figure, two layers of bluestone; the upper outcrops at an altitude of about 1500

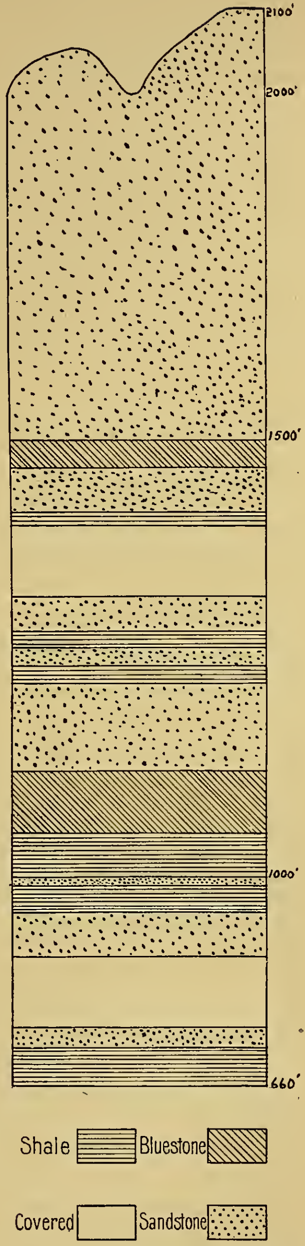

Fig. 2. —*Diagrammatic section through the two peaks west of Meads Gap*

feet, the lower, which outcrops on the southern slope of the mountain, is in this region covered with glacial drift. The strata as a whole dip gently west-northwest.

Glaciation

Two glacier streams have swept over this region:[3] the Continental Glacier, and later the more shallow Hudson Valley Glacier. The geologic structure of the region makes it somewhat difficult to trace satisfactorily the course of the glaciers; for the sandstones and soft shales of which the mountain is composed have retained glacial markings only in exceptional localities; while a considerable portion of the surface is, of course, covered with glacial drift.

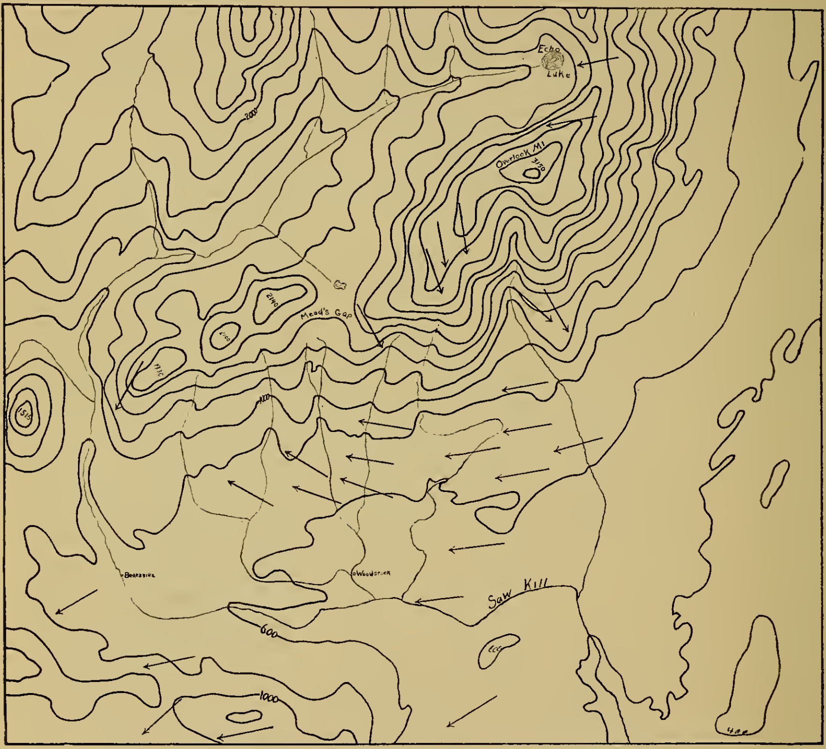

FIG. 3.—*Map of Overlook region, showing direction of glacial striæ (indicated by arrows)*
Contour interval 200 feet

The map (Fig. 3) shows the direction of the striations left by the Hudson Valley glacier in the Overlook region. It affords an interesting

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[3] A. A. JULIEN: "The Excavation of the bed of the Kaaterskill." Trans. N. Y. Acad. Sci., Vol. 1, p. 24-27. 1881.

example of the extent to which the direction of the ice near the surface can be affected by the topography. A variation of more than ninety degrees in the direction of the motion of the ice is indicated by the striæ on Overlook itself. Just northeast of Overlook, the course of the glacier was nearly south (S. 20° W.). A portion of it, however, flowed over the ridge between the Plattekill and Overlook Mountains and through what is now the upper valley of the Saw Kill in an almost westerly direction, moving nearly southward again through Meads Gap and at Shady. The ice moved almost directly west up the Woodstock Valley, its course becoming gradually more southerly as it passed over the group of low hills, known as the Ohio Mountain,[4] and the region farther south (S. 60° W. near Glenford and S. 40° W. at West Hurley).

MORAINES

While glacial action has probably not greatly altered the general outlines of the mountain, the valleys have been more or less filled with glacial deposits. A moraine nearly a mile long fills much of what was once the much deeper valley south of Meads Gap; while the upper valley of the Saw Kill, between Overlook and the mountain ridge to the north, is filled to a considerable depth with morainic material. Both of these are, in reality, parts of a large moraine which extends westward from Overlook.

As the moraines of the Catskills have been but little studied, a brief account of the material composing them may be of interest. About eighty per cent of it is of local origin, consisting of the sandstone, shale and conglomerate found throughout the Catskills. Of these materials, conglomerate is the least common and forms less than ten per cent of the whole. About one-half the local material consists of bowlders of various sizes, with which pebbles and gravel are mixed with no sign of stratification. From this it is apparent that water has played no part in the deposition.

The foreign material consists largely of quartz and several kinds of granite, with occasional pieces of water-worn, stratified rock and some sandstone containing brachiopodous shells. Some shells picked up in the bed of the Saw Kill, about two miles from its source, have been identified as *Spirifer arrectus*,[5] a species characteristic of the Oriskany sand-

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[4] This mountain is called "Tontshi Mt." on the U. S. G. S. topographic sheet. It seems, however, that this must be an error, as this elevation is locally known only as "Ohio Mt."; while the name "Tontshi" is applied to the much higher peak, left unnamed on the government map, just east of Ticetonik.

[5] The writer is indebted to Professor Charles Schuchert of Yale University for the identification of this specimen.

stone, a thin layer of which outcrops in the Little Catskills near the Hudson River due east from Overlook Mountain. It also appears in the Helderbergs to the northeast.

One rather unusual variety of metamorphic rock, several pieces of which were found, has been kindly identified by Professor J. F. Kemp of Columbia University, who writes: "It is a type of rock fairly well known in the Adirondacks. It has obviously been pretty well crushed and granulated, but it is a member of the anorthosite series, which when unchanged has large rectangular crystals of labradorite in a mass of small crystals of augite. . . . The rock outcrops at the very headwaters of the Schroon River in North Hudson township and also in the Keene Valley. I think it probably occurs in many other places, where it has not yet been specially observed. . . . In Bulletin No. 138 of the New York State Museum, on page 43, under the name of 'The New Pond Locality,' you will find a brief description of the rock."

That both the specimens just referred to are characteristic of the Adirondacks, together with the fact that all the metamorphic rocks found are common in those mountains, indicates that most of the foreign material in these moraines is of Adirondack origin.[6]

DRAINAGE

Except for a small portion of its eastern slope, Overlook is drained entirely by a single stream, the Saw Kill, which forms a loop, some ten miles or more in length, extending nearly around the mountain (Fig. 1). From its source in Echo Lake at the base of the northeastern ridge, it flows directly southwest through Shady, then east through the Woodstock Valley to a point directly south of its source. In the course of this loop, the Saw Kill receives the smaller streams which flow from both sides of the Overlook ridge. Owing to the small size of their watersheds, many of these smaller streams are dry during a part of the year. The rainfall is much greater in the spring than at any other season, and this gives rise to floods which make the erosive power of these streams much greater than it would otherwise be. The floods at this time are greatly increased by the melting of the winter's snow, and there is added the erosive force of the ice as it breaks up.

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[6] These moraines yielded more foreign bowlders than did the ones on the north side of the district, in the valley of Schoharie Creek, described by J. L. Rich in the *Journal of Geology*, vol. 14, p. 113, 1906, especially p. 120. Mr. Rich found but one bowlder of gneiss. It may be that later glacial action, radiating from local centers, had concealed earlier bowlders, brought in from the north. Mr. Rich's paper has also some general comments on the movement of the continental glacier, and, at the outset, upon the present conditions of rainfall.

Although no data as to the actual stream-flow on Overlook are at hand, a comparison of the flow of neighboring watersheds can not fail to be of interest in this connection. Fig. 4 gives the comparative discharge of the Schoharie, Esopus and Catskill Creeks for the different months over a period of years.[7] It shows that more than one-third of the total run-off of these streams occurs during two months, March and April. As the curves represent an average of several years, they give but little idea of the size of some of the floods. In the Schoharie, for instance, the maximum daily discharge in November, 1907, was 13,100 cubic feet per second, while for the same month, in 1908, the maximum was only 268 cubic feet per second.

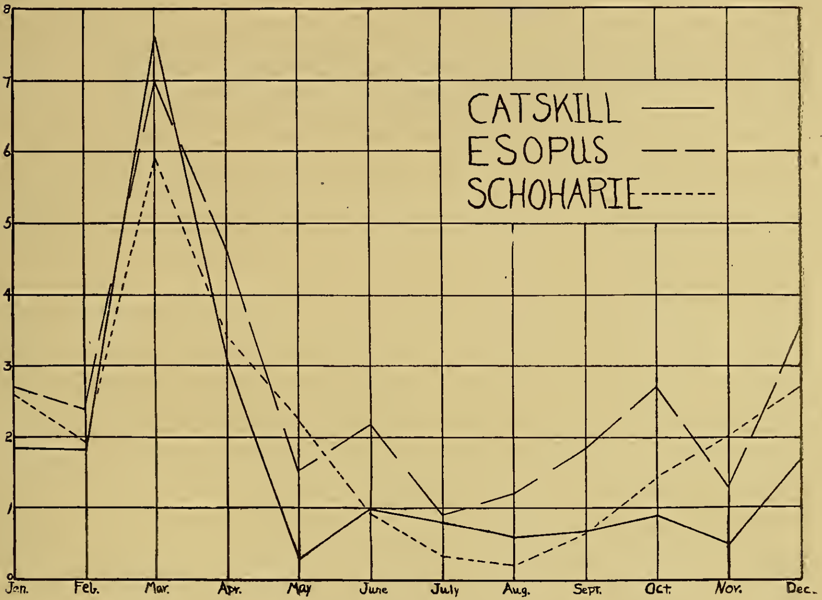

FIG. 4.—*Average discharge of the Catskill, Esopus and Schoharie Creeks for each month over a period of years*

Expressed in second-feet per square mile run-off. Taken as follows: Catskill Creek, South Cairo, N. Y., for period 1901 to 1905; Esopus Creek, Kingston, N. Y., for period 1901 to 1906; Schoharie Creek, Prattsville, N. Y., for period 1905 to 1908. Data compiled from Summary of the Climatological Data for the United States by sections. Section 104 (Weather Bureau); Water Supply and Irrigation Papers Nos. 166 and 202; and the Report of the State Engineer and Surveyor, State of New York, 1907 and 1908.

The valley of the Saw Kill is primarily of erosive origin. Like many

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[7] Records of rainfall, kept at Reservoir No. 1 of the Kingston City Water Works, indicate that the rainfall near Overlook is much like that of the other watersheds mentioned.

other valleys in the Catskills,[8] however, it was partly filled with debris by the continental glacier, so that now the Saw Kill, for the first five miles of its course, has cut its way through a moraine of varying height, 70 ft. at Shady, and 40 ft. half a mile below its source. This fact is clearly shown by the character of its bed, which is strewn with huge bowlders of bluestone, sandstone and conglomerate, together with smaller ones of granite and quartz, the harder ones still showing the marks of glacial action.

ECHO LAKE[9]

Echo Lake, the only considerable body of water near Overlook, is clearly of glacial origin. It is a shallow pond, about three hundred yards long by two hundred wide, and about eighteen feet deep in the deepest part, situated in the angle formed by the Plattekill and Overlook Mountains, just at the base of the high ridge connecting them. Across this deep valley, the moraine forms a huge natural dam which holds back the water of Echo Lake. The lake is thus bordered on three sides by high wooded ridges; while on the west, extending out over the moraine, is a swamp larger than the lake itself.

As is to be expected from its situation, Echo Lake is apparently decreasing in size rather rapidly. The swamp on its western side is slowly invading its waters. On this side, too, the lake is being narrowed by the action of its outlet, the Saw Kill, in cutting back through the Glacial drift which forms its bed. The pitch of the Saw Kill, which falls 1200 feet in the first four miles of its course, together with the floods mentioned above, makes this erosion relatively rapid.

In addition to this cutting away on its lower side, the lake is being rapidly filled in from above. The silt and leaf mold washed from the steep mountain ridges above the lake are deposited in the still water, and the amount of this material is very considerable. On the north and east this deposit forms a bed extending into the lake for more than two hundred feet and reaching a depth of four or five feet. Here the deposit is, to a considerable extent, protected from further action of the water by a dense growth of the yellow pond lily, *Nymphœa advena,* for which the fine silt and leaf mold furnish a favorable substratum. The combined effect of these agencies in reducing the size of the lake is so great as to make it probable that, at no very distant date, Echo Lake will be obliterated.

WASHINGTON, D. C.

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[8] JOHN C. SMOCK: "On the Surface Limit or Thickness of the Continental Glacier in New Jersey and Adjacent States." Am. Jour. Sci., vol. 25, pp. 339-350. 1883.

[9] Also known as Sheu's Lake.

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NOTES ON THE PRINCIPLES OF QUADRUPEDAL LOCOMOTION
AND OF THE
MECHANISM OF THE LIMBS IN HOOFED ANIMALS

BY

William K. Gregory

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CONTENTS

INTRODUCTION

The movements and locomotive mechanisms of animals were the subject of a classic work by Borelli in 1680, entitled "De Motu Animalium . . ." The chief pioneers of modern research were the brothers Weber (Eduard and Wilhelm), authors of "Die Mechanik der menschlichen Gehwerkzeuge," Göttingen, 1836. Marey, the author of the handbook on "Animal Mechanism"[1] (1874), invented elaborate apparatus for analyzing and graphically recording the movements of the limbs of men and animals, while more recently the mathematics of human locomotion have been developed by O. Fischer and others. General reviews of animal mechanics and of human locomotion are given by Marey,[2] Haycraft[3] and Luciani.[4] A very able analysis of the mechanism of locomotion in the horse is given in "The Horse in Motion," by J. D. Stillman,[5] while the extensive series of photographs by Muybridge[6] record the actual positions of the limbs and body assumed in motion by ungulates and other animals.

None of the above mentioned works considers the subject from the evolutionary point of view. Ryder,[7] and especially Cope,[8] pointed out certain adaptations in the feet of ungulates, such as the reduction of the digits in the "Diplarthra" and the so-called displacement of the metacarpals, and Cope used these observations in his argument for the hypothesis of the transmission of acquired characters. He also made the following very important observations:[9]

> "In animals which leap, the distal segments of the limbs are elongated; in those which do not leap, but which merely run or walk, it is the proximal segments of the limbs which are elongated.
>
> "Animals which run by leaping are divided into those which run and leap with all fours, as Diplarthra, and those which run and leap with the posterior limbs only, as the jerboas and kangaroos. In both types, the distal segments of the hind limbs are elongated, and in the Diplarthra, those of the fore limb also.
>
> "Animals which do not leap in progression (elephants, Quadrumana, bears) are always plantigrade and have very short feet but elongate thighs and mostly tibias."

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[1] 12mo. London, 1874.

[2] *Op. cit.*

[3] E. A. SCHÄFER: Text book of Physiology. Edinburgh and London, pp. 228-273, 1900.

[4] Physiologie des Menschen . . . Ins Deutsche übertragen and bearbeitet von Dr. Silvestro Baglioni und Dr. Hans Winterstein . . . Siebente Lieferung. Jena, 1906.

[5] Executed and published under the auspices of Leland Stanford, 4to, Boston, 1882.

[6] Animals in Motion . . . Third Impression 4to, London, 1907.

[7] Am. Nat., vol. 11, p. 607. 1877.

[8] "The Mechanical Causes of the Development of the Hard Parts of the Mammalia." Journ. of Morphology, vol. 3, pp. 137-290. 1889.

[9] *Ibid.*, p. 151.

Cope neglected to follow up the important mechanical and adaptive corollaries of these facts. He merely drew the very questionable inference that "those elements which receive the principal impact in progression are those which increase in length [in phylogeny]."[10]

In his paper on "The Angulation of the Limbs of Proboscidia, Dinocerata, and other Quadrupeds, in Adaptation to Weight," Osborn[11] concluded that

> "The straightening of the limb [in the Dinocerata, Proboscidia, etc.] is an adaptation designed to transmit the increasing weight through a vertical shaft. Correlated with it are the shifting of the facets into the direct line of pressure and the alteration of their planes from an oblique to a right or horizontal angle with relation to the vertical shaft."

Gaudry,[12] in describing the limbs of extinct South American ungulates, endeavored to show how the pose of these animals could be inferred from a study of the facets,—an idea which had been previously advanced by Osborn.[13] Gaudry also designated as "rectigrade" the pose of elephants and similar heavy forms which stand with straightened limbs and toes, resting the weight chiefly on the pad.

The marked contrasts in the limbs and musculature between the slow-moving heavy-bodied ungulates and the slender swift-footed or cursorial types in various phyla, constitute a subject which will be discussed in considerable detail in the monograph on the Titanotheres by Professor Osborn. At his suggestion, the following notes, forming a part of the present writer's studies on this subject, are now published, together with some of the drawings which have been made by Mr. Erwin S. Christman, under the direction of the writer, for the monograph above mentioned. The writer is also indebted to Dr. W. D. Matthew for valuable criticisms and suggestions.

Limbs regarded as Compound Levers

The simple principle that the limbs of quadrupeds are compound levers and that the relative lengths of the upper, middle and lower segments are adapted to specific loads, muscular powers and speeds, although well understood by students of human and equine locomotion, has apparently not hitherto been applied to elucidate the adaptive contrasts between cursorial and "graviportal"[14] ungulates.

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[10] *Loc cit.*

[11] Am. Nat., vol. xxxiv, pp. 89-94. 1900.

[12] "Fossiles de Patagonie. Les Attitudes de quelques Animaux." Ann. de Paléontologie, tomei.

[13] "Patriofelis and Oxyæna restudied as Terrestrial Creodonts." Bull. Amer. Mus. Nat. Hist., Vol. 13, pp. 270, 271. 1900.

[14] This word has been invented by Professor Osborn to describe the conditions in heavy-bodied animals with long proximal and short distal limb segments.

Evolutionary Stages of Quadrupedal Locomotion

In the Stegocephalian stage of quadrupedal locomotion, the short limbs were held widely outward from the body, the humerus and femur were very short and the feet were spreading and flat. Crawling was effected in part by a sharp downward pull of a proximal segment (humerus or femur), thus tilting the body upward on the same side and throwing the weight on the opposite foot. The long axis of the body was meanwhile thrown into alternate lateral curves, the advancing fore limb being on a convexity, the advancing hind limb on a concavity.

In the late reptilian or early mammalian stage, the feet were brought around partly under the body, the elbow and knee began to be drawn in, the scapula was rotated backward as the coracoid lost its connection with the sternum, and the body became well raised off the ground. According to a hypothesis advanced elsewhere by the writer,[15] this process was associated with the acquisition of climbing, or semi-arboreal, habits, structural vestiges of which remain in the partly divergent first digit and many other characters of early Eocene mammals.[16]

The Lower Eocene ancestors of the various orders of ungulates had probably all long since passed through these earlier stages of quadrupedal terrestrial locomotion, and at that time many of them had perhaps become more or less digitigrade. The primitive "Protungulates," *Meniscotherium, Periptychus, Pantolambda,* may give us some idea of what the several ancestors of the subungulate series (Hyracoidea, Embrithopoda, Proboscidea, Amblypoda) may have been like. They also preserve apparent traces of arboreal ancestry in the relatively short, spreading hands and feet, long limb bones, the humerus with large entocondyle and entepicondylar foramen, the undiminished power of pronation and supination of the forearm and many other characters. The Basal Eocene *Euprotogonia,* the ancestor of the Condylarth *Phenacodus,* with slender subunguligrade feet, represents a more advanced stage of evolution, in the direction of the Perissodactyls.

Factors of long-distance Travelling Power in Ungulates

The primitive ungulates of the Lower Eocene were doubtless surrounded by environmental conditions which set the premium of survival upon improvements in long-distance travelling power and in speed. These improvements have been attained in various ways and in the most

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[15] "The Orders of Mammals," Bull. Amer. Mus. Nat. Hist., Vol. 27, p. 226, 1910.

[16] Matthew: Arboreal Ancestry of the Mammalia, Amer. Nat., Vol. 38, 1904, pp. 811-818.

diverse lines of evolution,—in the elephant no less than in the antelope. The general factors of long-distance travelling power may be grouped broadly under the headings: (A) Endurance and (B) Speed.

A. ENDURANCE

Endurance may be measured either by (1) the length of time an ungulate can keep in motion without rest or refreshment, or by (2) the amount of reserve strength left after a stated expenditure of energy, or by (3) the relative quickness of recuperation. Endurance increases with practice. As metabolism increases, the muscles, lungs, heart and other organs of the thorax become stronger and larger.

More rapid metabolism requires more food and larger digestive apparatus. Although the Lamarckian hypothesis in its crude form is very probably untenable, it is a fact that herbivorous animals have longer and heavier digestive tracts than carnivores. Moreover, as fast as the dentition has become adapted for the harder, less nutritious kinds of food, the digestive apparatus must have become more complex and much heavier.

While the enlarging thorax and abdomen have made available a great increase in energy, they have caused an even more rapid increase in total weight.

With increasing total weight, the internal and external resistance to be overcome in locomotion also rises, and hence the margin between the total energy available and the energy required in progressing a given distance is lessened. In other words, endurance, the first great factor of long-distance travelling power, is directly proportional to the efficiency of the adaptations for minimizing the waste of energy.

ADAPTATIONS FOR MINIMIZING WASTE OF ENERGY

Higher efficiency in locomotion has doubtless been attained, first, by advantageous modifications of the organs of propulsion (such as are described below), secondly, by improvements in the supporting framework, thirdly, by improvements in the methods (*a*) of conserving the inertia of forward motion, (*b*) of taking up shock, (*c*) of preventing dislocation and (*d*) of minimizing lost motion.

Momentum.—The shocks and strains to which the locomotive apparatus is subject vary with the momentum of the body in motion. Hence as momentum is the product of mass by velocity, the shocks and strains experienced by heavy animals in rapid motion are very great, and devices for lessening them become conspicuous.

Propulsion and the center of gravity.—"Perfect quadrupedal locomotion," says Stillman,[17] "requires uniform support to the center of gravity (of the whole animal) and continuous propulsion by each extremity in turn." In walking and running, by the straightening or extension of the limbs, the center of gravity is raised and thrown in advance of the centers of support. The body thus falls forward, the center of gravity describing a curve of greater or less convexity, the forward motion being accelerated by the thrust of the propelling limb.

The first shock of the downward fall in the running horse is taken up by the forwardly stretched and slightly bent hind limb (Fig. 1) placed beneath or in advance of the center of gravity; the gradually stiffening muscles of the thigh and back checking the downward momentum (Stillman, p. 91). The rearing muscles thus come into play and serve to let the fore part of the body down gently.

Dislocation of the fully extended forelimb in landing is prevented partly by (*a*) the crutch-like action of the limb itself (which is slung from the converging fibers of the serratus magnus attached to the top of the scapula) and by (*b*) the contraction of certain muscles of the shoulder, neck and back (Stillman, pp. 61, 62, *et seq.*). To these arrangements and conditions, Stillman attributes the absence of the clavicles in the horse.

The center of gravity in the smoothly trotting horse describes a relatively flat trajectory, whereas in the "bounding" movement, or gallop, the center of gravity ricochets and the trajectory consists of a series of cycloids of marked convexity. This mode of locomotion, while very rapid for short distances, is too wasteful for heavy-bodied animals, which require a relatively flat trajectory and a maximum saving of inertia.

Sinuous movement of the body in running.—By the bending backward of the pelvis, first on one side and then on the other, the thrusts of the femora are brought more nearly into line with the anteroposterior axis, while wrenching of the pelvis is prevented by the contraction of the longissimus dorsi of the opposite side (Stillman, p. 36). By this means also, the length of the stride is directly increased. The same sinuous motion of the body is associated with the "figure-of-8" movement of the limbs noticed by Pettigrew.[18]

In this connection may be noted also the devices for avoiding "interference" of the limbs (*e. g.*, "stifle action" of the iliacus, preventing the knee from striking the abdomen; oblique trochlea of the astragalus carrying the advancing foot around its fellow of the opposite side). Dislocation

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[17] *Op. cit.*, p. 87.

[18] Animal Locomotion, p. 39. 12mo. New York, 1874.

is provided against not only by the ligaments, but also by the metapodial keels, by the grooved trochlea of the astragalus, by the cnemial crest of the tibia, etc.

Spiral configuration of limb bones and of articular surfaces.—Goodsir, Pettigrew[19] and others have shown that the articular surfaces of the elbow, ankle and calcaneo-astragalar joints are spirally warped surfaces which act after the manner of screws. The limbs as a whole also are twisted levers with the ridges and muscles arranged spirally. "This arrangement," says Pettigrew, "enables the higher animals to apply their traveling surfaces to the media on which they are destined to operate at any degree of obliquity so as to obtain a maximum of support or propulsion with a minimum of slip. If the traveling surfaces of animals did not form screws structurally and functionally, they could neither seize nor let go the fulcra on which they act with the requisite rapidity to secure speed, particularly in water and air."

Lost motion.—Lost motion through backward slipping of the foot upon the ground is provided against in the horse by the form and details of the hoof, and in the elephant by the plantar pads.

Pendulum action of the limbs.—The brothers Weber held that in rapid locomotion the limbs swing freely as pendula, but Marey and later investigators, according to Luciani,[20] hold that the natural swing of the leg is very largely damped and controlled by the flexor muscles. In favor of the view that there is some measure of analogy to the pendulum, we observe that in the horse, the center of gravity of the limb, corresponding to the "bob" of a pendulum, is relatively proximal in position, and this is associated with rapid oscillation of the limb, whereas in the elephant, the center of gravity of the limb is farther down the shaft, and here we have a slower oscillation of the limb. It will be observed that while the body is moving forward, the propelling limb is moving backward, and its own backward momentum, due to weight alone and to the pull of the extensors, must be overcome by the forward pull of the flexor muscles and by the forward pull of the body as a whole. Hence the heavier the limb, the greater the force expended in overcoming and reversing the momentum of each limb at the end of each stride.

SPEED

The speed of a quadruped or biped in motion is measured by the product of the length of the stride into the rapidity of the stride.

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[19] Animal Locomotion, pp. 23-24, 28, 29. 1874.

[20] *Op. cit.*, p. 126.

The diverse adaptations in the limbs, considered as compound levers, are related to either or both of the factors, "length of stride" and "rapidity of stride."

LENGTH OF STRIDE

Length of limb.—Length of limb is the first factor of length of stride. It is generally proportional to height at the shoulders and hips. Length of limb has been attained in cursorial animals by lengthening the lower and middle segments of the limb, in graviportal animals by lengthening especially the proximal segments of the limb.

Angle of stride.—Angle of stride is the second factor. It is measured by the arc described by the lower end of the femur or humerus in swinging from the position of extreme extension to that of extreme flexion. A wide angle of stride not only lengthens the stride, but also enables each limb, first, to be placed in turn below or beyond the center of gravity in order to secure more continuous support for the center of gravity, and, secondly, it enables the propelling limb to exert its propulsive effort for a relatively long period.

Acceleration increment of stride due to ballistic power of limbs.—Those portions of the stride that are due simply to the length of the limb and to the angle of the stride might, if determined, be illustrated by moving the inert limbs of a dead animal suspended in the air. In the slow walk of a biped, the successive positions of the legs might for our purposes be represented by a series of inverted V's (Λ Λ Λ Λ Λ Λ) with the lower ends touching. Each Λ represents a single step and two successive Λ's represent a stride. In the rapidly moving animal, however, the stride receives a very considerable increment, due to the impetus imparted by the propelling limb and to the forward motion of the body as a whole, which carries the forwardly moving foot to a position far in advance of its own unaided reach. This "acceleration increment," as it may be called, increases with the velocity of the movement and is proportional to what we may designate the ballistic power of the limb. This ballistic power may be defined as excess propulsive power over and above that which is necessary to move the limbs as stilts and to support the weight of the body; it is expended in lengthening the stride. Ballistic power and the acceleration increment of the stride are measured by the length of time at least three of the feet are off the ground together during a single stride of a quadruped running at full speed. In Fig. 1, representing an elephant in rapid motion (ambling), it will be observed that three of the feet are never off the ground at the same instant; whereas Stillman's Figs. 2-10 show a galloping horse in which at least three of the feet are off the ground at once in seven out of nine phases of one stride. The same figures show that the elephant has three feet on the ground together during five-sixths of one stride, and during the remaining sixth the body is supported by one fore foot and the opposite hind foot, whereas the horse in question never has three feet on the ground together during the stride there pictured. Thus it will be seen that the "acceleration increment" of the stride and the ballistic power of the limbs are at a maximum in cursorial animals and at a minimum in graviportal animals. The "acceleration increment" will no doubt increase also with the potency of the psychic motive and of the neural stimulus (cf., p. 282).

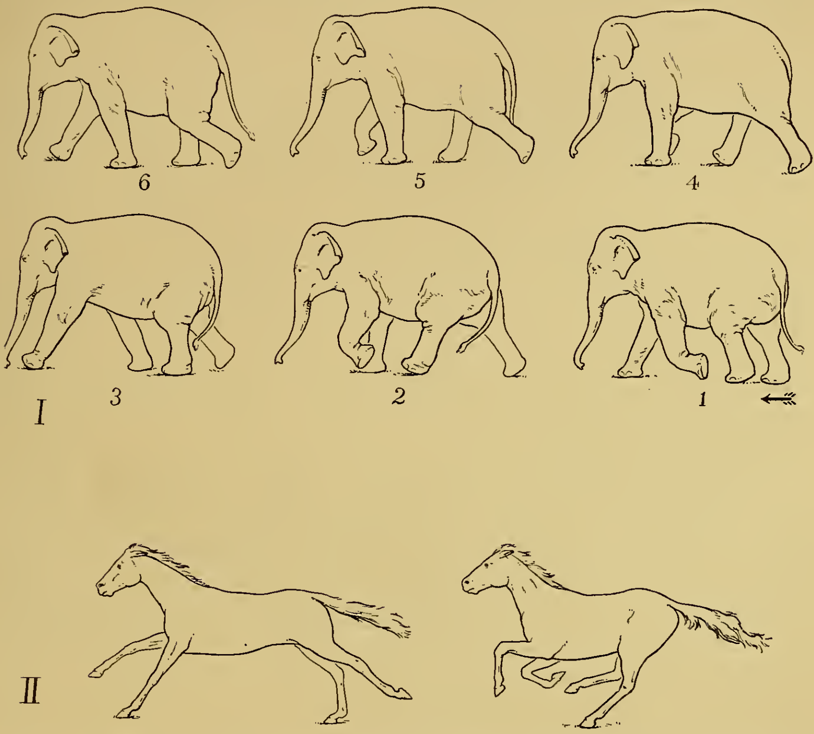

Fig. 1.—*Graviportal and cursorial modes of locomotion contrasted in the amble of the elephant (I) and gallop of the horse (II)*

I after Muybridge; II after Stillman

In brief, the factors of length of stride are (1) length of limb, (2) angle of stride, (3) acceleration increment.

RAPIDITY OF STRIDE

Rapidity of stride, the second major factor of speed, is determined by the rate of oscillation of the limbs, especially of the proximal segments. The conditions determining rapidity of stride are discussed below (p. 281).

MECHANICAL AND PHYSIOLOGICAL RELATIONS OF POWER AND SPEED IN THE LOCOMOTIVE APPARATUS

CONTRACTILE FORCE OF LOCOMOTIVE MUSCLES

The contractile force of a muscle (*i. e.*, its ability to overcome inertia at a given instant) is proportional to the number of its contractile fibers, when these fibers are parallel to the direction of contraction. The force of such a muscle is therefore proportional to the sectional area of the muscle.[21] In the case of weights lifted vertically by isolated muscles, the work (W) performed is measured by the product of the muscular force (F), multiplied by the distance (D) through which the load is lifted[22] ($W = F \times D$). This distance is proportional to the length of the muscle,[23] for the "shortening" of a muscle is proportional to its length. Hence the total work performed will be proportional both to the length of the muscle and to its sectional area, and hence to the mass or the weight of the muscle.[24]

The work performed by a long muscle is greater than that of a shorter one of the same sectional area.[25] Long and slender muscles such as the sterno-mastoid and the sartorius of man exert a small power over a long range; short and thick muscles such as the pectoralis major, the glutæus maximus or the temporalis develop a relatively great power multiplied by a short range.[26] The contractile force of muscle per unit of sectional area is much less in cold-blooded than in warm-blooded animals.[27] It is lessened by disuse and extreme fatigue and is increased by exercise, and hence is dependent upon the nervous system and general systemic conditions.

The contractile force is inversely proportional to the number of connective tissue fibers mingled with the striped muscle fibers. Hence muscles grade into tendons and ligaments. When a muscle is stretched,

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[21] HAYCRAFT in Schäfer's Text book of Physiology, p. 242.
[22] *Ibid.*, p. 245.
[23] *Ibid.*, p. 244.
[24] *Ibid.*, p. 246; also Marey, p. 62. 1874.
[25] HAYCRAFT, p. 246.
[26] MAREY, p. 62.
[27] HAYCRAFT, p. 243.

it serves partly as a ligament. All muscles *in situ* are stretched to a certain degree, and thus act as ligaments.[28] "Over extension" of the muscle is prevented by the inextensible connective tissue fibers.[29] According to Stillman,[30] the length of the muscles cannot be increased by exercise, otherwise the tension necessary to prompt action would be lost.

The contractile force is highest when a muscle is stretched to its full "physiological length" (that is the greatest length it ever assumes during life). As shortening takes place, the contractile force becomes less and less (Haycraft).[31]

Contractile force and speed of movement augmented by "hold and let go" arrangements.—Fick and Helmholtz showed[32] that the greatest force and velocity of contraction are developed when the movement of the muscle is checked during the initial stages and when the resistance is suddenly diminished.

Amount of contraction.—The shortening of individual muscles is in general proportional to their length when in repose, but different investigators give somewhat different estimates. "While Weber described a muscle as shortening 70 per cent. of its length, when unweighted, more recent observers incline to put the shortening at 20 to 30 per cent. of its length" (Haycraft).[33] Marey[34] estimates "the mean shortening of a muscle while contracting, when it is not detached from the animal," as "about a third of its length when in repose." Bishop's estimate is one-fourth (Stillman, p. 31). "When the fibers are not parallel, but obliquely set, as in the gastrocnemius, we have a greatly extended transverse area of muscular fibers, which act therefore very powerfully, though, on account of their short length, they can exercise their pull but a comparatively short distance" (Haycraft).[35]

THE "ANGLE OF INSERTION" AND THE PRINCIPLE OF THE PARALLELOGRAM OF FORCES

In Fig. 2 (I), let AC represent a rod free to rotate around the point A in the direction CC′; let BD represent a contractile spring fastened at D, inserted on AC at B and forming the angle ABD (α). Assume that the length of BD is proportional to its contractile force; then from

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[28] *Ibid.*, p. 245.

[29] *Ibid.*, p. 242.

[30] *Op. cit.*, p. 32.

[31] *Op. cit.*, p. 242.

[32] HAYCRAFT, *op. cit.*, p. 248.

[33] *Op. cit.*, p. 244.

[34] *Op. cit.*, p. 62.

[35] *Op. cit.*, p. 242.

the principle of the parallelogram of forces, we may resolve BD into two forces, the first AB acting in the direction of the rod AC and tending to press AC against its fulcrum A, the second component BR acting at right angles to the first and tangent to the arc of rotation BB′. The first component AB may be called the "centripetal component," the second BR may be called the "rotation component." In Fig. 2 (II), the contractile spring *bd* is of the same length as before, but the angle of insertion *abd* (*a*′) is increased; then the centripetal component *ab* will be less than AB, but the "rotation component" *br* will be greater than BR. Accordingly as the angle of insertion increases, the pull *across* the shaft becomes more direct, while the pull *along* the shaft decreases; in other words, the rotation component varies directly, the centripetal component inversely, with the angle of insertion.

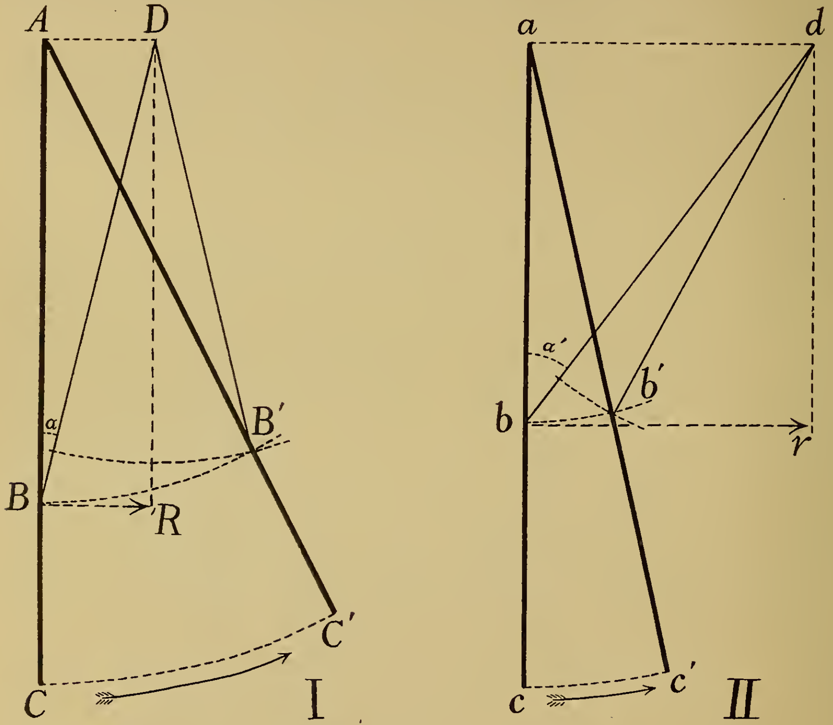

FIG. 2.—*Diagram illustrating the direct relation of the angle of insertion (a, a′) to the "rotation component" (BR, br) and the inverse relation of the angle of insertion (a, a′) to the "centripetal component" (AB, ab) and to the speed of the insertion point (proportional to BB′, bb′).*

Applying this to Fig. 6, II, we see that in the horse, the muscles figured are inserted at more open angles of insertion (α, β, γ) than in the mastodon or elephant and that their rotation components are therefore relatively greater, the centripetal components relatively less.

The foregoing principles were worked out independently by the writer, but Luciani[36] gives similar principles for human locomotion. He states that not all of the muscular force is available for the movement of the skeleton, that this is only the case when the insertion of the muscle on the bone reaches almost a right angle, as in the case of the masseters, which can exert their whole strength in pressing the lower jaw against the upper jaw. He says that generally, owing to the conditioning form of the skeleton, the muscle is attached more or less obliquely, so that the direction of its fibers makes a more or less acute angle with the long axis of the bone. In all these cases, a great part of the total force of the muscle is lost as regards movement. In every case, however, whatever the form of the muscle or the size of the angle of insertion may be, by resolving the total pull into its components, in accordance with the law of the parallelogram of forces, one can determine how much of the total pull is expended in the movement of the bone, assuming the other bones to be stationary. Luciani[37] also shows that the more acute the angle of insertion is, the smaller will be the component of rotation, and the nearer the angle of insertion approaches a right angle, the greater will be the component of rotation.

Relations of speed of movement and angle of insertion.—Returning to Fig. 2, we see that if DB contracts to DB′, the point of insertion will move from B to B′. If now the angle of insertion be increased to α' and *db* (equal to DB) contracts to *db′* (equal to DB′), then the point of insertion moves only through *bb′*, which is less than BB′. If the contraction time as well as the distance be constant, then B will move faster than *b*; that is, when the rate of contraction and length of muscle are constant the speed of the insertion point varies inversely with the angle of insertion.

It is also evident that if the angle of insertion and other factors remain constant the speed of the distal end of a long bone will increase as the point of insertion is moved toward the head of the bone. (Because BC will be larger.)

Variableness of the rotation component.—From Fig. 2, it will be seen that the angle *ab′d* is somewhat greater than *abd*, that is, both the angle of insertion and the rotation component increase as the muscle contracts.

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[36] Physiologie des Menschen, Siebente Lieferung, p. 115.

[37] *Ibid.*, p 116.

"MOMENT OF RESISTANCE" AND "DIMINISHING LOAD"

In every lever, whether of the first, second or third order, the "power" and the "resistance," acting along parallel lines, but in opposite directions, are in equilibrium when the power multiplied by its effective distance from the fulcrum is equal to the resistance multiplied by its effective distance from the fulcrum. The "effective distance" is measured by a line passing through the fulcrum and perpendicular to the line of direction of the force. The product of a force multiplied by its effective distance from the fulcrum is called its "moment."

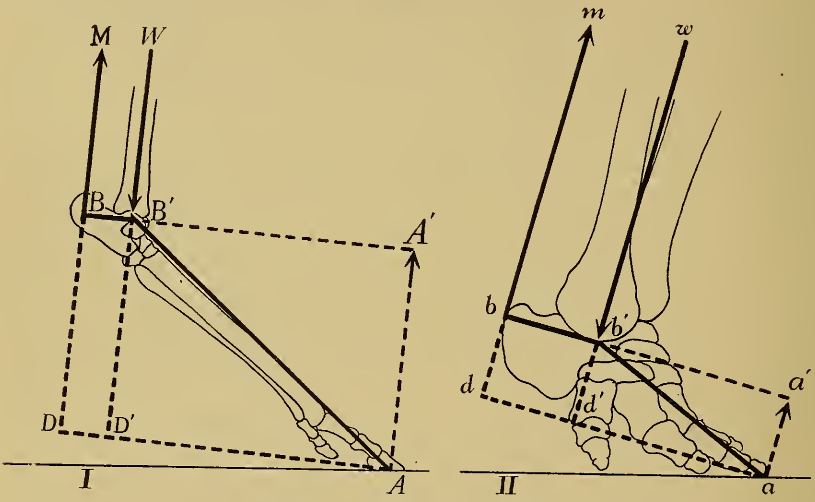

FIG. 3.—*I. Hindfoot of an extremely cursorial type (Neohipparion) showing at the instant of greatest extension of the foot a low moment of power of the calf muscles* ($M \times BB'$) *and a very high moment of resistance* ($W \times B'A'$) *of the pressure of the tibia upon the ankle.*

II. Hindfoot of an extremely graviportal type (Mastodon) showing at the instant of greatest extension of the foot a much higher moment of power of the calf muscles ($m \times bb'$) *and a relatively lower moment of resistance* ($w \times b'a'$) *of the pressure of the tibia upon the ankle.*

In Fig. 3, I, it would appear natural to assume that the point A, on the ground, is the fulcrum, and that the "resistance" is the pressure of the tibia upon the ankle joint at B′, while the "power" is the contractile force of the muscles of the calf, applied at B. Similarly, Eduard Weber[38] described the human foot as a lever of the second order and gave for the relations of the forces and movements of the foot in raising the

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[38] Cf. HAYCRAFT, *op. cit.*, p. 251.

weight of the body a formula which translated into the terms of our Fig. 3 would be as follows:

$$M \times BA' = W \times B'A'$$

But Knorz, Henke, Ewald and others, as quoted by Haycraft (*loc. cit.*), showed that the effective distance of the muscular force M is not BA', but BB', and that we should rather conceive the foot as a lever of the first order with the pivot at B', the "power" at B and the "resistance" (offered by the reaction of the ground upon the foot) at A. In that case, the moments around B' are as follows:

$$M \times BB' = W \times B'A'$$

Hence, other things being equal, the longer the foot, the greater will be the moment of resistance to be overcome by the muscles of the calf.

If the angle B'AD' be increased, as when the foot assumes a more vertical position, the effective distance B'A' decreases; that is, the moment of resistance decreases as the foot becomes more vertical. In other words, the "load" diminishes as the calf muscles contract. It has been shown by Fick and others (quoted by Haycraft, *loc. cit.*, p. 246) that when the force of muscular contraction is opposed to a diminishing moment of resistance, the muscle is capable of performing more total work (force × distance) than when the resistance is constant. Consequently, the diminishing resistance, conditioned by the raising of the foot, enables the calf muscles to perform their work under the most favorable conditions.

SUMMARY OF MECHANICAL AND PSYCHIC FACTORS IN POWER AND SPEED

The speed of the distal end of a "long bone" of the limbs will depend upon (1) the nearness of the point of insertion of the principal muscles to the joint or axle, (2) the smallness of the angle of insertion of the muscles, (3) the position of the muscle fibers with reference to the long axis of the muscle, and (4) the speed of contraction of the muscle itself. If a long muscle and a short muscle were isolated for experiment, it might prove that the short muscle would contract faster than the long one, but, in nature, a single movement of a long bone is produced by the simultaneous and coördinated action of muscles of varying length. Thus, in the act of extending the whole arm from the fully flexed position, the relatively short, broad thoraco-scapular and scapulo-humeral muscles contract in the same time as do the relatively long extensors of the forearm, irrespective of their lengths. The speed and force of contraction naturally depend partly upon the strength of the stimulus and partly on the resistance to be overcome.[39] The end result, as it were, determines the rate of contraction of the coördinated muscles. The effective regulation and correlation of muscular action is obviously an extremely complex function of the peripheral and central nervous systems. The force and speed of contraction of a given set of muscles in a living animal at a given moment are determined not only by many mechanical factors, of which a few have been mentioned above, but also by the whole psychic constitution of the animal and by the psychic effectiveness of the exciting "motive."

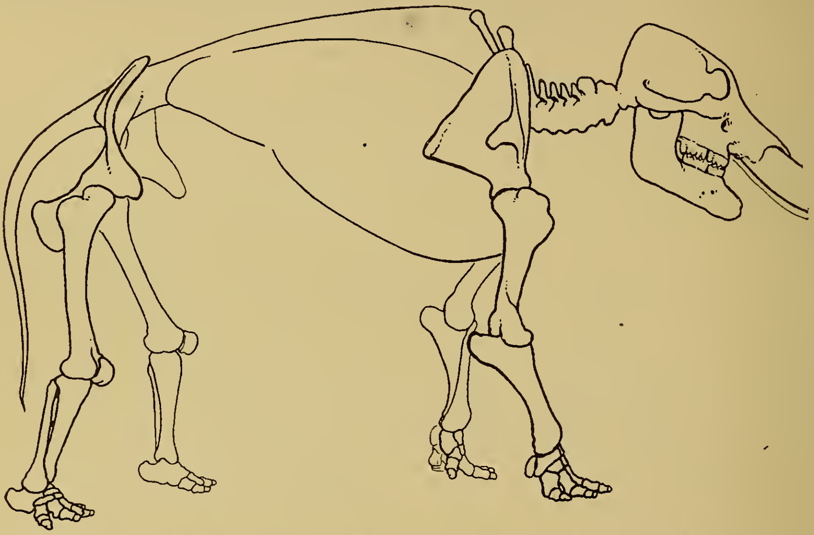

FIG. 4.—*"Graviportal" adaptations for the walk and amble in the Mastodon*

APPLICATION OF THE FOREGOING PRINCIPLES TO THE STUDY OF THE LIMBS OF UNGULATES

FUNCTIONAL SIGNIFICANCE OF THE ANGULATION OF THE LIMBS

As noted above (p. 269), the straightness of the limbs in the Proboscidea and similar heavy-bodied animals was interpreted by Osborn in 1900 as "an adaptation designed to transmit the increasing weight through a vertical shaft." While this is no doubt an incidental advantage of the straightness of the limbs, it is probably not the chief teleological "object." From a consideration of the mechanical principles governing the use of the limbs as compound levers (see pp. 278-281) and

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[39] J. BURDON SANDERSON, in Schäfer's Text Book of Physiology, Vol. 2, p. 363, 1900.

from a comparison of the photographs (Fig. 1) of an ambling elephant and of a galloping horse, it seems probable that the straightness of the limbs in graviportal animals has been evolved *pari passu* with the short rectigrade feet and with an ambling even gait, in combination with a long stride of minimal acceleration increment (p. 274). Conversely, the bent or angulate character of the limbs in the horse and other cursorial animals is correlated in part with the very long, slender unguligrade feet and with a bounding galloping or trotting gait, in combination with a long, very rapid stride of maximal acceleration increment.

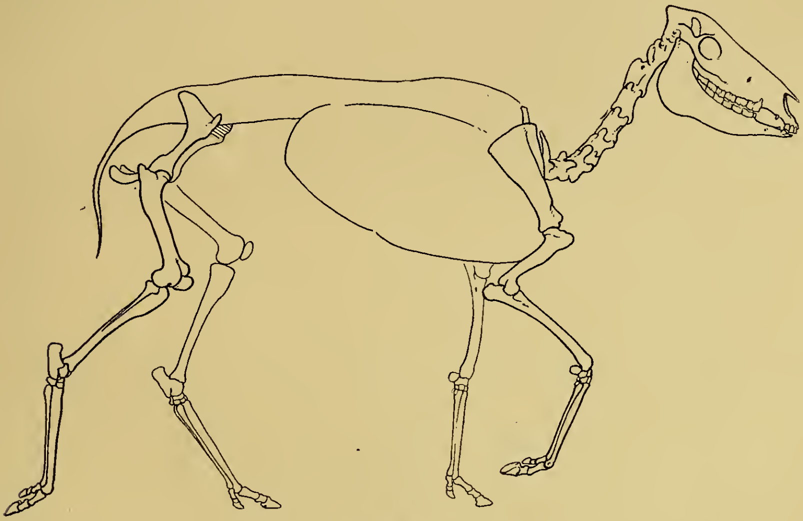

FIG. 5.—*"Cursorial" adaptations for the run, gallop, etc., in the Neohipparion*

In other words, the use and structure of the feet have been the teleological dominants which have determined the diverse modifications in the musculature, proportions and angulation of the proximal segments of the limbs, just as in early stages of aquatic adaptation in reptiles (*e. g.*, Thalattosuchia, Nothosauria, etc.) the aquatic habits are reflected more clearly in the feet or distal segments rather than in the proximal limb segments.

MECHANICS OF THE FOOT IN GRAVIPORTAL AND CURSORIAL FORMS

Comparing the structure and function of the graviportal and cursorial types of feet, we see (Figs. 3 and 4) that, in the elephant, the very massive gastrocnemius and soleus muscles are attached at a wide angle to the massive calcaneum, while the foot itself is very short. In the position shown in Fig. 3 (II) and as compared with conditions in the horse, this gives a relatively high moment of power (proportional to bb') to the calf muscles and a relatively low "moment of resistance" (proportional to $b'a'$) to the great pressure of the shaft of the limb upon the astragalus. A considerable part of this "moment of resistance" is also subtracted by the supporting effect of the great pad of elastic tissue underneath the foot. No doubt the specimen from which Fig. 3, II, was drawn should have been mounted with the feet more nearly vertical; this would greatly shorten $b'a'$ and further increase the advantage of $m \times bb'$. As the plantar pad is raised from the ground, more weight is thrown on the toes, but, at the same time, they are brought further back almost beneath the astragalus, thus reducing $b'a'$ to a minimum, so that the load decreases as the muscles contract. This arrangement not only compensates for the fact that the greatest absolute force of a muscle is developed when it is stretched to its full psysiological length, but it also permits the muscle to perform a greater total quantity of work than would be the case if the load were increasing instead of diminishing (p. 280).

Similarly, in the horse, the greatest "moment of resistance" is when the foot is fully flexed forward (which is at the instant the foot touches the ground); the action of the extensor muscles is thus suddenly checked; this conditions physiologically a corresponding and sudden increase in the available energy (p. 277). By the raising of the heel the moment of resistance ($W \times BA'$), as in the case of the elephant, also decreases, *i. e.*, the load diminishes; but in the elephant, the motion of the foot is relatively slow and the acceleration increment of the stride (p. 275) is therefore slight, whereas in the horse the motion of the foot is very rapid, and the acceleration increment (through the high velocity imparted to the relatively light body by the spring-like extension or opening of the angles at the stifle, hock, fetlock and pastern) is very great, so much so that at least three of the feet are off the ground during a great portion of the time. In brief, short feet (as in the Proboscidea) slightly bending at the ankle, raise a heavy load through a short distance with a minimal acceleration increment of the stride; long feet (as in the horse), sharply bending at the ankle, throw a smaller load a long distance, with a maximal acceleration increment.

Metatarso-femoral ratios.[40]—That in cursorial animals the hind foot is long as compared with the femur, while in graviportal animals the

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[40] The investigation of limb- and arch-form and proportions, and especially the establishment and significance of definite ratios between the limb segments, were suggested by Professor Osborn and taken up conjointly by him and the writer in the Eocene section of the Titanothere Monograph; the following observations on limb ratios are in part a preliminary publication of the joint results attained.

reverse is the case, is shown by the table of ratios, Plate XXXIV, and especially in the following examples:

$$\text{Ratio}: \frac{\text{Length of metatarsal III}}{\text{Length of femur}}$$

Graviportal		*Mediportal*		*Subcursorial*		*Cursorial*	
Coryphodon	.14	Rhinoceros	.37	Eohippus	.50	Equus	.78
Uintatherium	.10	Palæosyops	.21	Tragulus	.56	Antilope	1.00
Mastodon	.11			Mesohippus	.57	Odocoileus	1.00
Elephas	.13						
Brontotherium	.20						
Toxodon	.17						

These ratios definitely prove the connection between the mode of locomotion and the length of the middle metatarsal as compared with the femur. The wide differences in the metatarso-femoral ratio, ranging from .10 in extreme graviportal forms to 1.00 and upward in cursorial forms, are partly bridged over in the mediportal and subcursorial types, and even more completely in a fifth group including certain primitive ungulates, the Condylarths, in which $\frac{\text{Mts. III.}}{\text{F.}}$ ranges from .43 to .31.

Perhaps the most important facts to keep in mind in comparing these and similar ratios (below) are that the ancestral Placentals probably had relatively short hands and feet and long limb bones (p. 270), but that there was doubtless a considerable range of variation in this respect even as far back as the Upper Cretaceous epoch. We are unfortunately unable to follow the ratios through approximate phyletic series except in a few cases (especially Titanotheres, Equidæ, Rhinocerotidæ), but, in every case, we can feel sure that the precise ratios attained in the end-forms are conditioned largely by the nature of the ratios in the stem-forms of each family.

Thus, the exceptional shortness of the feet in the Amblypoda is conditioned by the fact that this group, as represented by *Pantolambda*, had comparatively short feet before gigantism was developed. *Hyrax* is another example of a small form with very short feet, and from some such forms the Proboscidea probably arose.

Besides those phyla which had short feet in the ancestral forms and which merely emphasized this feature, there are many phyla which started from animals with feet of moderate length and later shortened up the feet to a considerable extent. Thus in the Titanotheres, the oldest and most primitive form (*Eotitanops*) has a metatarso-femoral ratio of about .34, which is not far from that of other early Perissodactyls, but in the collateral descendants of *Eotitanops,* we observe a relative shortening of the digits, correlated with increasing body size and straightening of the knees, so that $\frac{\text{Mts. III.}}{\text{F.}}$ drops from .34 through .31 and .30 in the Middle Eocene genera to .28, .26 and even .20 in the gigantic *Brontotherium.* Again, in the Rhinoceroses, the oldest, smallest and most primitive forms have a foot of moderate length ($\frac{\text{Mts. III.}}{\text{F.}} = .43\text{-}42$), but by progressive relative shortening and broadening, the ratio drops to .24 in *Metamynodon.* In the Hippopotami, which are probably descended from animals proportioned about as in *Oreodon* (with an index of .38), gigantism and aquatic habits have brought about a reduction of the index to .26. Similarly in the Toxodonts, the smaller and more primitive forms had relative long, slender feet, while in the gigantic *Toxodon* $\frac{\text{Mts. III.}}{\text{F.}}$ falls to .17.

In those groups in which the most primitive known members had already attained a slender foot, with reduced side toes, gigantism is unable to effect a complete approximation to the graviportal type. Thus, in the bisons, which are undoubtedly descended from slender-footed forms having a metatarso-femoral ratio not less perhaps than .75, the sudden increase in size causes the ratio to fall but slightly (to .65). In the gigantic Irish elk, whose ancestors probably had a very high metatarso-femoral ratio (perhaps 1.00 or more), this ratio falls to .71.

The evolution of cursorial forms is also indicated by marked changes in the ratio under consideration. Thus, in the Equidæ, it rises from .53 in *Eohippus,* through .68 in *Mesohippus* to .99 in *Hypohippus,* reaching the extreme of 1.16 in the slender-limbed Upper Miocene horse, *Neohipparion.* In the relatively small and slender kiang, the ratio is still 1.00, but in the relatively heavy-bodied *Equus scotti* of the Pleistocene, the ratio is only .84, while in modern horses, we observe even in race horses a falling off of the index to .78, and in the stocky-limbed *Hippidion,* it drops to .72. Correlated with this fall in the length of the metatarsal III, we observe a straightening of the knee. These figures possibly may mean that the modern *Equus caballus,* on account of its great size, is somewhat less adapted to extreme cursorial locomotion than was the slender *Neohipparion* which closely paralleled the deer *Odocoileus.*[41] On the other hand, race horses seem to have comparatively long femora (*cf.* Stillman, p. 80) and cheetahs, hounds and other

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[41] J. W. Gidley: Bull. Amer. Mus. Nat. Hist., Vol. 19, pp. 474-476. 1903.

forms that progress by bounding have quite long femora. In this connection, it must be remembered (p. 278) that a long femur, implying small angles of insertion of the principal extensors, gives relatively high speed of rotation of the insertion points, but low power for the rotation components. The long femur of graviportal forms has a wholly different meaning (p. 289).

Progressive reduction of the side toes in the Artiodactyla as in the Perissodactyla is accompanied by the elongation of the cannon bone (here represented by two coalesced digits, metatarsals III. and IV.) and by other cursorial adaptations. The primitive Artiodactyl foot with four complete side toes is represented in *Oreodon,* which has a ratio of .38. In *Sus* the ratio is .34, in the primitive four-toed camel *Eotylopus reedi* it rises to .52, in *Tragulus* to .66, whence it rises rapidly to 1.00 and more in the deer and antelopes, culminating in 1.35, an extreme figure, in the giraffe. In the giraffe, the development of great body size has not brought about any reduction in the length of the metacarpals, but, in correlation with the long neck, has even lengthened them.

Other adaptive contrasts in the feet.—There are other adaptive contrasts in the feet of graviportal and cursorial animals, as follows:

In graviportal forms, the astragalus is flattened down, for, when the weight of the body is raised, it is easier to force the tibia up a gentle slope than a steep one. No lateral keels are needed on the trochlear surface to prevent dislocation because of the breadth and spreading character of the tarsus and of the large size of the fibular malleolus. In cursorial animals, on the contrary, the curvature of the astragalar trochlear is steep and the range of movement wide; the trochlea keels help to keep the narrow tarsus in place.

With regard to the phalanges, in cursorial animals, the sharp bending at the fetlock and pasterns and the sudden straightening out of these joints under the pull of the powerful flexors of the foot greatly assists in projecting the body into the air (Stillman, *loc. cit.,* p. 89).

In graviportal animals, on the other hand, the terminal phalanges are reduced; the massive flexors of the foot raise the weight slowly and assist the animal in rolling from one foot to the other.

GRAVIPORTAL AND CURSORIAL TYPES OF TIBIA

Some of the tibio-femoral ratios $\left(\frac{T}{F}\right)$ given on Plate XXXIV may here be grouped as follows:

Graviportal

Uintatherium	.53
Coryphodon	.61
Pyrotherium	.56
Mastodon	.69
Elephas indicus	.60
Brontotherium	.54
Metamynodon	.58
Teleoceras	.57

Subcursorial or Primitive

Phenacodus primævus	.84
" wortmani	.97
Euprotogonia	1.01
Meniscotherium	.91
Procavia	.97
Hyrachyus	.95
Sus scrofa	.86
Eotylopus	.96

Mediportal

Palæosyops	.77
Rhinoceros indicus	.79
Tapirus	.80
Pantolambda	.76

Cursorial

Eohippus	1.00
Mesohippus	1.08
Neohipparion	1.17
Equus caballus	.92
" scotti	.88
Tragulus	1.09
Odocoileus	1.16
Gazella	1.25
Antilope	1.21
Antilocapra	1 23

These figures express the fact noted by Osborn, that, in general, graviportal forms have relatively a short tibia and long femur, while cursorial forms have a long tibia and short femur. It is highly probable that in the remote ancestors of all the Placental orders, the tibia was long, perhaps about as long as the femur. The primitive combination of long tibia and short feet is retained in *Meniscotherium, Hyrax* and to a less degree in *Euprotogonia, Phenacodus wortmani* and *Eohippus.* The steps through which the shortening of the tibia in graviportal animals has been attained may in some cases be discerned. Thus in the Amblypoda, the small and primitive *Pantolambda* has a tibio-femoral ratio of .76; in *Coryphodon,* this ratio falls to .61 and in the huge *Uintatherium* to .53; similarly in the titanotheres, the ratio drops from .77 in *Palæosyops* to .54 in the massive *Brontotherium.* In the Rhinoceroses, it falls from .95 (*Hyrachyus*) to .79 (*Rhinoceros*) and .58 (*Metamynodon*).

In the extremely cursorial lines, the long tibia of primitive mammals was usually lengthened slightly, but in the heavier members of cursorial phyla (*e. g., Equus, Bison*), we observe occasionally a falling off in the ratio.

The difference between the shortest graviportal tibia (*Uintatherium,* ratio .53) and the longest cursorial tibia (*Gazella,* 1.25) is much less extreme than in the metatarso-femoral ratios, which range from .11 to

1.35. There are also more ratios of intermediate type. Consequently, the tibio-femoral ratios taken alone do not always furnish a sure indication of the mode of locomotion.

From the viewpoint of adaptation, there are several plausible reasons why the tibia has not shortened to so extreme a degree as has the middle metatarsal. A short tibia implies a low knee joint and a long femur. A long femur, as stated below, is associated with a nearly vertical innominate bone and with narrow angles of insertion of the principal long muscles (Fig. 6). The result of these small angles of insertion is that the long muscles exert a powerful pull in the direction of the shaft of the femur (p. 278 and Fig. 2), an arrangement favorable to the lifting and support of great weight (p. 290). The short tibia and

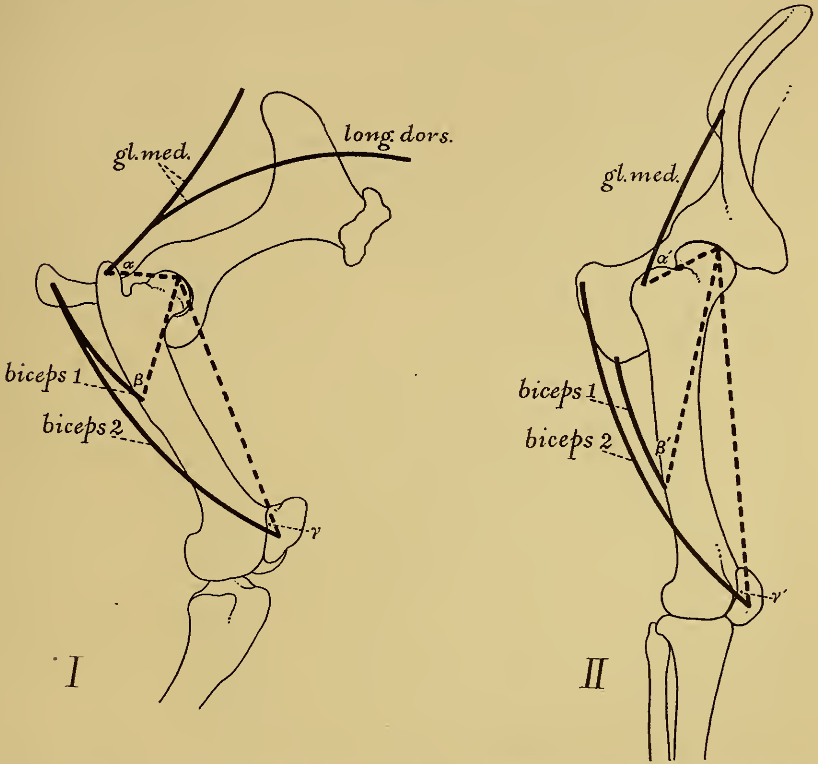

FIG. 6.—*Relations of certain extensor muscles to the pelvis and femur in the standing pose in (I) a typically cursorial form, the Horse, with relatively wide angles of insertion (α, β, γ), and in (II) a typically graviportal form, the Mastodon, with narrow angles of insertion (α′, β′, γ′).*

The heavy black lines represent the general directions of the muscles; the broken lines represent the radii of rotation of the insertion points.

short foot, conditioning a low knee joint, also enable the very heavy animal to rise from the ground with comparative ease. At the same time, excessive shortening of the tibia (as in Ground Sloths) probably conditions very slow motion, which would be very disadvantageous to an animal that has to wander far in search of food.

GRAVIPORTAL AND CURSORIAL TYPES OF FEMUR

The femur of primitive animals (Creodonts, Condylarths, Stem Perissodactyls, etc.) is long, when compared with the size of the body. It has a prominent third trochanter situated in the upper fourth of the shaft and serving for the insertion of the glutæus superficials (seu maximus). This muscle arises from the enlarged tuber coxæ of the ilium and apparently functions as an adductor of the femur. The trochanter major projects high above the shaft.

These characters persist in the cursorial types, the chief difference being that here, as a rule, the femur is relatively short when compared with the size of the body. The short femur is associated with a subhorizontal innominate bone and with comparatively open angles of insertion of the long muscles (Fig. 6, I), which pull across the long axis of the femur and give high components of rotation and relatively low centripetal components (in the direction of the shaft of the bone). Such an arrangement, associated as it is with cursorial adaptations, seems less adapted for the support of a great dead weight than that noticed above in graviportal animals. In the standing pose, a sharp angulation at the knee conditions a tendency for the leg to collapse, which is counteracted by the stretching and tension of the opposing flexors and extensors of the thigh (Fig. 7). In the horse, these opposite tensions are transmitted by means of special tendons on opposite sides of the leg, which also serve to tie as it were the limb in position and thus relieve the muscles to a considerable extent. In graviportal animals, the long muscles are also stretched in standing and thus serve as ligaments, and since they are inserted at very narrow angles, their centripetal components are relatively high (p. 278).

In the femur of graviportal animals, the third trochanter is often reduced, absent or confluent with a long ridge running down from the great trochanter and situated well down the shaft. The functional meaning of this is possibly that the glutæus superficialis is less developed in graviportal animals, its place, perhaps, being usurped by the greatly enlarged glutæus medius. Again, it is conceivable that the third trochanter may have been crowded out, so to speak, by the enlargement of the powerful vastus muscles, which arise on the femur just above the third trochanter and which are one of the chief muscles used in lifting the body at the hips. The great trochanter of graviportal animals is very broad and heavy, but is more or less sessile, not jutting up so much

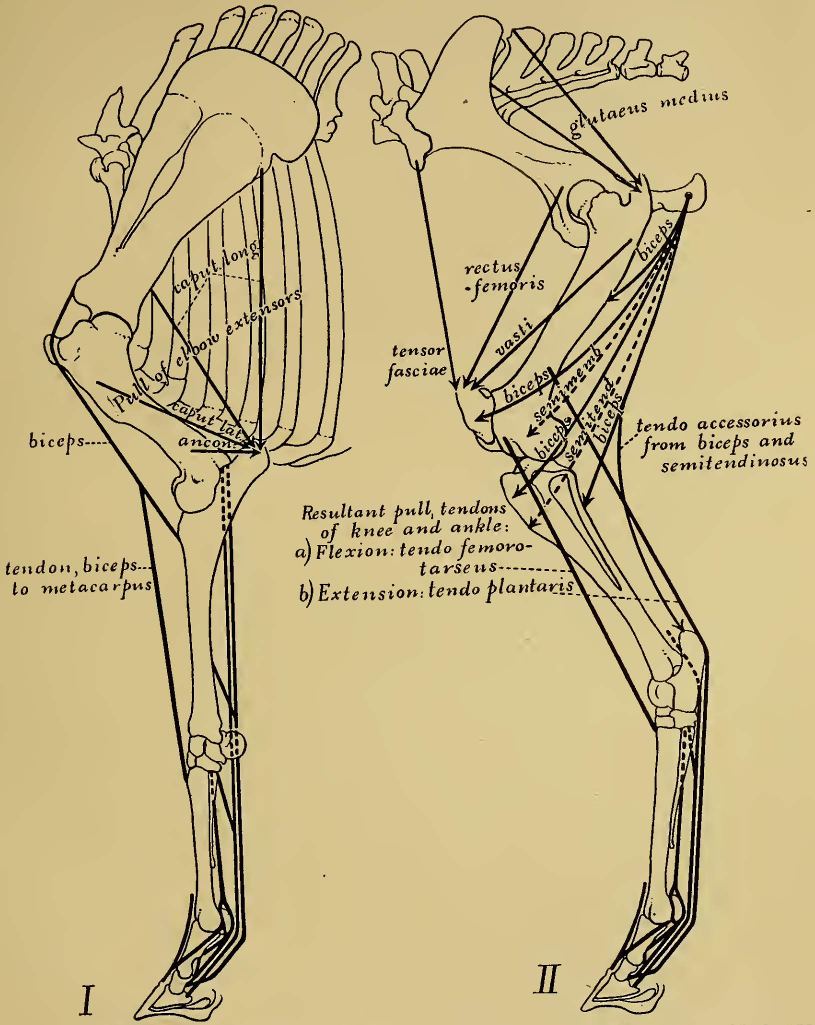

FIG. 7.—*The tendons and muscle-pulls which hold in place the fore- (I) and hind- (II) limbs of the standing horse*

After Schmalz

above the head of the bone. The reason is that the massive glutæus medius is inserted more upon the flat top and outer side of this projection than upon its anterointernal slope (Fig. 6, II), a fact correlated with the subvertical position of the ilium.

In brief, the long femur of graviportal animals serves for the attachment of long and very massive flexor and extensive muscles inserted at slight angles; it brings the knee joint well down below the belly, and it is further characterized by a very heavy sessile great trochanter and a more or less reduced third trochanter, located far down the shaft; the distal facets, as observed by Osborn, are more or less at right angles to the shaft, so that the femur rests subvertically upon the tibia.

GRAVIPORTAL AND CURSORIAL TYPES OF PELVIS

(Figs. 4-6)

The upper anterior border of the ilium in cursorial animals is concave, so that the anterior part of the glutæus medius is produced in front of the ilium and inserted into a long fossa in the posterior end of the fascia covering the longissimus dorsi.[42] The result is that these two muscles apparently pull in tandem, while the subhorizontal position of the pelvis permits the glutæus medius to be inserted on the great trochanter at an angle approaching a right angle. Thus the powerful and prolonged contraction of the combined glutæus medius and longissimus dorsi is exerted well across the long axis of the femur, producing a very powerful rotation component. Similarly the subhorizontal position of the ischium opens out the angles of insertion of the three branches of the biceps and of other extensors and flexors of the thigh.

In such progressively graviportal lines as the Amynodontinæ among the Rhinoceroses, we observe the transformation of the cursorial into the graviportal pelvis by the filling out of the anterosuperior concavity of the ilium, the broadening of the ilium and outward growth of the tuber coxæ and the increasing verticality of the whole pelvis. The result of these changes with regard to the muscles is that the glutæus medius is separated by a wall of bone from the longissimus dorsi, the insertion space of the glutæus medius and accessorius is greatly increased and the medius passes down subvertically on to the broad trochanter major of the femur; the angles of insertion of the flexors and extensors also lessen. Such graviportal adaptations have taken place independently in many lines of ungulates (Amblypoda, Proboscidea, Titanotheres, Amynodonts, Toxodonts) and also in the ground sloths.

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[42] R. SCHMALTZ: "Atlas der Anatomie des Pferdes." Zweiter Teil: Topographische Myologie, Taf. 27 u. 28. 4to, Berlin, 1909.

GRAVIPORTAL AND CURSORIAL TYPES OF FORE LIMB

Much of what has been said above regarding the mechanical advantages of short hind feet in moving a heavy load or of long feet in throwing forward a light load applies also to the fore feet. The table of ratios (Plate XXXIV), however, shows that in both graviportal and cursorial types, the third metacarpal is usually longer in proportion to the radius than is the third metatarsal to the femur. The radius also is usually much longer in proportion to the humerus than is the tibia to the femur and the radiohumeral ratio responds less clearly to changes in mode of locomotion than does the tibiofemoral ratio. The adaptive reasons for these facts are not altogether clear, but they must be conditioned partly upon the marked differences in form and musculature between the shoulder girdle and the pelvis and upon the different situations of the fore and hind limbs with respect to the center of gravity of the animal. The relatively long metacarpals and long radius even of graviportal animals gives a very long reach to the fore arm, as shown in Fig. 1, I. In some graviportal animals, as in the Proboscidea, the humerus is much longer than the scapula, the elbow is widely exserted from the body and is turned outward in the back stroke, thus bringing the wrists well in. Interference is avoided by the sharp pronation of the radius, so that during flexion of the wrist the palm of the manus is turned partly outward. In this type of scapula, the backward extension of the posterior angle of the blade, as well as the length of the humerus, gives space for a very heavy caput longus of the triceps, which thus also secures a more direct upward pull on the olecranon. The postspinous fossa is located almost directly above the posterior part of the great tuberosity of the humerus, so that the pull of the infraspinatus muscle is nearly vertical. The tuber spinæ of the scapula is greatly enlarged, its upper border for the trapezius, its lower for the heavy deltoideus. In some other graviportal types (*e. g.*, *Toxodon*, *Rhinoceros*), the scapula instead of being broad and short is narrow and high, with vertically extended pre- and postspinous fossæ. In some cursorial types (*e. g.*, *Equus*), the scapula is also long, with rather narrow pre- and postspinous fossæ; in others (*e. g.*, Pecora), the scapula is fan-shaped, truncate at top, with prespinous fossa reduced and postspinous fossa much developed.

Regarding the relative power of the fore and hind limbs, many people think that in the horse, the hind limbs furnish much more than half of the locomotive power, but Stillman arrays cogent evidence[43] tending to

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[43] *Op. cit.*, pp. 69, 79, 89.

show that the fore feet, drawn backward by the great pectoral triceps and powerful back muscles, contribute more than their share to the general result.

DIAGNOSTIC VS. CONVERGENT EVOLUTION VALUE OF LIMB RATIOS

From inspection of the table (Plate XXXIV), it will be seen that, allowing for imperfection of the fossil material and incompleteness of the series, the limb ratios have a certain degree of diagnostic value when taken in groups and that pure convergent evolution rarely brings about a close agreement in all four ratios at once.

The best cases of convergent evolution noted are as follows:

			$\frac{\text{Mts. III}}{\text{F.}}$	$\frac{\text{T.}}{\text{F.}}$	$\frac{\text{Mtc. III}}{\text{H}}$	$\frac{\text{R}}{\text{H}}$
Cursorial...	Perissodactyla...	Neohipparion......	1.01	1.17	1.16	1.30
	Artiodactyla.....	Odocoileus..........	1.00	1.16	1.05	1.12
Traviportal.	Edentata.........	Lestodon	.12	.51	.17	.60
	Amblypoda.....	Coryphodon	.14	.61	.19	.66
Mediportal.	Titanotheriidæ...	Brontops robustus..	.26	.55	.37	.82
	Amynodontidæ..	Metamynodon	.24	.58	.39	.81
	Rhinocerotidæ...	Teleoceras..........	.25	.57	.37	.78
	Toxodontia......	Toxodon	.17	.56	.38	.77

The greatest extremes are found in the following:

Traviportal.	Amblypoda......	Uintatherium......	.10	.53	.19	.70
Cursorial...	Giraffidæ........	Giraffa	1.35	1.18	1.42	1.60

COMPARATIVE TABLE OF LIMB RATIOS IN THE HOOFED MAMMALS.

Species.	emur (F)	etatarsal III (Mts. III)	ts. III/F (F=1)	ibia (T)	F (F=1)	umerus (H)	etacarpal III (Mtc. III)	tc. III/H (H=1)	adius (R)	H (H=1)
Suidæ										
Sus scrofa	248	86	.34	215	.86	208	77	.37	168	.80
Hippopotamidæ										
Hippotamus amphibius	498	130	.26	332	.67	395	152	.38	270	.68
Camelidæ										
Eotylopus reedi	148	78	.52	142	.96	118	68	.57	100	.84
Camelus arabicus	470	325	.60	400	.80	363	330	.90	455	1.25
Tragulidæ										
Tragulus napu	94	62	.66	103	1.09	74	42	.56	62	.83
Cervidæ										
Odocoileus hemionus	253	255	1.00	295	1.16	198	208	1.05	223	1.12
Cervus megaceros	430	350	.71	454	1.05	334	342	1.02	358	1.07
Bovidæ										
Gazella dorcas juv.	140	132	.81	176	1.25	93	134	1.44	118	1.26
Antilope cervicapra	183	183	1.00	223	1.21	133	180	1.35	168	1.26
Bison bison	369	243	.65	355	.96	290	198	.60	293	1.01
Antilocapridæ										
Antilocapra americana	210	218	1.03	260	1.23	164	213	1.30	202	1.23
Giraffidæ										
Giraffa sp.	466	630	1.35	550	1.18	435	618	1.42	698	1.60

e—Estimated.

COMPARATIVE TABLE OF LIMB RATIOS IN THE HOOFED MAMMALS.

Species.	Femur (F)	Metatarsal III (Mts. III)	$\frac{\text{Mts. III}}{\text{F}}$ (F=1)	Tibia (T)	$\frac{\text{T}}{\text{F}}$ (F=1)	Humerus (H)	Metacarpal III (Mtc. III)	$\frac{\text{Mtc. III}}{\text{H}}$ (H=1)	Radius (R)	$\frac{\text{R}}{\text{H}}$ (H=1)
	mm.	mm.		mm.		mm.	mm.		mm.	
CONDYLARTHRA										
Euprotogonia puercensis	105	45	.43	107	1.01	......	.....	......	......	......
Phenacodus wortmani	134	51	.38	131 ? 138 r	.97 1.00	107	36	.65	89	.83
Phenacodus primævus	234	74	.31	198	.84	167	70	.42	146	.87
Meniscotherium terrærubræ	100	29	.29	91	.91	82	22	.27	58	.70
AMBLYPOOA										
Pantolambda bathmodon	149	36	.24	114	.76	124	31	.25	82	.66
Coryphodon lobatus	423	62	.14	260	.61	363	70	.19	240	.66
Uintatherium (Dinoceras) mirabile	692	70	.10	360	.53	540	106	.19	380	.70
PYROTHERIA										
Pyrotherium (figd. by Gaudry)	622	......	......	351	.56	452	......	......	238	.52
PROBOSCIDEA										
Mastodon americanus	1,020 c	117	.11	705	.69	885	165	.18	670	.75
Elephas indicus	1,020	138	.13	618	.60	810	183	.22	685	.80
E. (Loxodonta) africanus	1,050	144	.13	755	.71	1,000	205	.20	870	.87
HYRACOIDEA										
Procavia sp.	71	19	.26	69	.97	69	16	.23	46	.66
TOXODONTIA										
Toxodon sp.	577	101	.17	325	.56	387	147	.38	298	.77
EDENTATA GRAVIGRADA										
Hapalops sp.	150	18	.12	108	.72	130	22	.16	106	.80
Lestodon armatus	640	78	.12	330	.51	530	94	.17	325	.60
PERISSODACTYLA TAPIROIDEA										
Heptodon calciculus	175	75 e	.43	175	1.00	115	67	.58	114	.99
Tapirus americanus	262	108	.41	208	.79	205	106	.50	177	.86
Tapirus indicus	320	120	.37	258	.80	250	120	.48	228	.91
PERISSODACTYLA RHINOCEROTOIDEA										
Hyrachyus agrarius	254	110	.43	243	.95	197	93	.47	197	1.00
Hyracodon nebrascensis	267	114	.42	220	.82	202	114	.56	210	1.03
Rhinoceros indicus	495	180	.37	395	.79	385	186	.48	385	1.00
Teleoceras fossiger	408	105	.25	233	.57	305 c	114	.37	238	.78
Metamynodon planifrons	480	118	.24	280	.58	393	153	.39	320	.81
PERISSODACTYLA TITANOTHEROIDEA										
Eotitanops borealis	250 e	? 86	? .34	......	......	203	85	.41	......	......
Palæosyops major	433	137	.31	332	.77	......	.....	......	......	......
Palæosyops leidyi	370	110	.30	290	.78	325	? 113	? .34	235	.72
Palæosyops sp. (A. M. N. H. No. 12205	.....	......	......	......	......	? 340	106	.30	237	? .69
Limnohyops sp. (A. M. N. H. No. 11689	355 e	111	.31	285	.79	293	109	.37	228	.77
" " " " No. 11690	367	123	.31	283	.73	......	......	......	.....	......
Manteoceras manteoceras	? 390	......	......	272	.69	......	......	......	......	......
Mesatirhinus petersoni, No. 11659	358	118	.33	283	.79	......	......	......	......	......
Dolichorhinus hyognathus, No. 13164	386	119 e	.30	......	......	315 e	.....	......	284	? .81
Titanotherium trigonoceros	770	220 e	.28	430	.55	620	240	.38	520	.83
Brontops robustus	812	212 e	.26	448	.55	608	230	.37	504	.82
Brontotherium gigas ♀ (518 A. M.)	780	200	.20	427	.54	528	214	.40	478	.90
PERISSODACTYLA HIPPOIDEA										
Eohippus sp.	162	82 e	.50	162	1.00	121	64	.53	110	.90
Mesohippus sp.	178	121	.68	193	1.08	136	92	.68	136 e	1.00
Hypohippus osborni	278	218	.78	277	1.00	205	203	.99	260	1.27
Neohipparion whitneyi	249	252	1.01	293	1.17	187	218	1.16	244	1.30
Equus kiang	313	277	.88	310	.99	237	238	1.00	302	1.27
Equus scotti	370	263	.71	330	.88	289	243	.84	342	1.18
Equus caballus (race horse)	392	288	.73	363	.92	305	240	.78	363	1.19
Hippidion neogæum	340	214	.62	305	.89	273	198	.72	287	1.05
ARTIODACTYLA										
Oreodontidæ										
Oredon culbertsoni	161	62	.38	142	.88	138	57	.41	113	.81
Suidæ										
Sus scrofa	248	86	.34	215	.86	208	77	.37	168	.80
Hippopotamidæ										
Hippotamus amphibius	498	130	.26	332	.67	395	152	.38	270	.68
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GEOLOGIC AGE OF THE BEDFORD SHALE OF OHIO

BY

George H. Girty

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GEOLOGIC AGE OF THE BEDFORD SHALE OF OHIO[1]

BY GEORGE H. GIRTY

(Presented in abstract before the Academy, 7 October, 1912)

The Bedford shale takes its name from Bedford, in Cuyahoga County, Ohio. The typical locality is the gorge of Tinkers Creek below the falls, where the formation comprises about 75 feet of bluish clay shale lying between the Berea sandstone above and the black slaty Cleveland shale below. To the west, the lower portion of the Bedford develops a sandstone member which is quarried as the "Cleveland bluestone," while the upper portion undergoes a change of color to a strong red. In fact, the Bedford is better known as a red than a blue formation.

The fossils of the Bedford shale are largely confined to the basal portion, though a few species are represented by rare individuals at higher horizons. At Bedford, fossils are abundant in immediate contact with the Cleveland shale, where they are more or less crushed, and also a few feet higher in large calcareous concretions, where the surface characters are apt to be obscured. Some of them are broken and rounded as if by wave or current action, but this is not the general character of their occurrence.

The Bedford shale lies close to what has been considered the boundary between the Devonian and Carboniferous systems, and it is the purpose of the present paper to present such evidence as I have bearing on the geologic age of the formation. The question then is whether the Bedford shale shall be included in the Devonian or the Carboniferous system. I shall treat this largely as a paleontologic question, and my fossil evidence is derived from typical sections at Bedford and other points in Cuyahoga County.

It will not be out of place to consider some of the principles controlling such an attempt as I have taken in hand.

Theoretically, the great geologic systems were defined by movements creating extraordinary changes in the conditions of land and water, always undergoing changes more or less gradual, and these conditions entailed corresponding changes in the character of the plants and animals which had in them their habitat. As expressed lithologically, the rocks of the several systems, perhaps generally in the typical region and not infre-

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[1] Published by permission of the Director of the U. S. Geological Survey.

quently in regions far removed, show a basal sandstone or conglomerate with more or less pronounced evidence of preceding erosion or uplift. Such events though often far reaching must in the broadest sense have been only local, but we may fairly expect the more subtile changes of environment, such as depth, temperature, currents, which govern the character and distribution of animal life, to have extended far beyond the area of great disturbance, and we may look for evidence of such disturbance in the fossil floras and faunas, when none is to be found in the rocks themselves or their relation to one another. In fact, such paleontologic evidence may have been all but universal. Conglomerates and unconformities and faunal changes occur at other horizons than the division lines between systems, but such evidence will be of great importance in deciding the point in question.

In addition to the kinds of evidence already mentioned as often accompanying the transition from one geologic system to another, that is, an interval of erosion, a basal sandstone or conglomerate and a well-marked faunal change, there are also certain other considerations of a more adventitious or incidental nature. For practical purposes, it would be unfortunate if this line (that between two systems), which of all lines it is desirable to represent on a geologic map, were taken where it could with difficulty be recognized in the field, as in the middle of a uniform lithologic interval, or where the evidence would often be concealed, as would be the case in some regions if it were assumed to lie between two formations of soft and easily disintegrated material. Furthermore, the importance of convention also enters the consideration. Other things being equal, it is clearly preferable to take for the boundary which is sought the same horizon at which it has been drawn elsewhere, if that horizon can be determined.

The boundary between the Berea sandstone and the Bedford shale in some degree satisfies all these requirements. It is easily recognized and easily traced; it also appears to be the locus of an unconformity.[2] The Berea answers to the basal conglomerate of theory. While the Bedford seems properly to form part of the great shale series which preceded it, the Berea marks the change to another and different type of sedimentation. The passage from Bedford to Berea is also marked by an abrupt and strong faunal change. Not only are the two faunas widely different, but the Bedford has a preponderant Devonian facies and the Berea a preponderant Carboniferous facies. To some extent, the faunal change at

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[2] This erosional unconformity was clearly stated by Newberry as early as 1874 (Ohio Geol. Survey, Geol., vol. 2, p. 91). More recently it has been mentioned by J. E. Hyde (Jour. Geol., vol. 19, 1911, p. 257) and described by W. G. Burroughs (*idem*, p. 655).

the top of the Bedford is offset by one equally marked in the opposite direction, between the Bedford shale and the Chagrin shale. In support of this statement I shall not feel called upon to submit evidence, because in so far as it is untrue, the Devonian affinities of the Bedford faunas are by so much stronger than they are here represented. Finally, the determination of the boundary between the Devonian and Carboniferous at the base of the Berea satisfies to some extent the canon of convention. This is true, however, only from one point of view, for if the Berea ("Corry") sandstone correlates with the Kinderhook beds of the Mississippi Valley which represent the base of the Carboniferous system in its type section, and if some horizon below (?) the Chagrin correlates with the Chemung group which represents the top of the Devonian in its type section,[3] the canon of convention or usage would be ambiguous in its bearing upon these intermediate beds whether they should be classed with one system or the other, because by one approach they would be found above the recognized top of the Devonian, just as by the other they would be found below the recognized base of the Carboniferous.

This too is only partly true, however, because Hall[4] classed as Chemung, or more often "Upper Chemung," the intermediate group of strata here under consideration, so that, although their stratigraphic position is above the Chemung proper and therefore theoretically above the top of the Devonian, they have in practice been included all along in that system. Incidentally, this circumstance seems to show Hall's opinion of the affinities of the "Bradfordian" faunas,[5] though it must be remembered that he correlated with the Chemung the Waverly group lying still above.

Now the statements which it is proposed to present the evidence for and to discuss are the following: the faunal change incident to the passage from the Bedford shale to the Berea sandstone; the Carboniferous aspect of the Berea fauna, and its probable correlation with the Kinderhook of the Mississippi Valley; the Devonian aspect of the Bedford fauna, and the relation of the Cuyahoga, Berea and Bedford faunas to those of the typical Mississippian sections of Missouri, Illinois and Iowa.

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[3] The typical sections of the Devonian and Carboniferous in the United States are meant. The original sections are of course in Europe.

[4] This statement is based upon the fact that Hall described and included in the Chemung fauna numerous pelecypods from many of the well-known "Bradfordian" localities of Pennsylvania.

[5] Here and elsewhere in this paper, "Bradfordian" is employed in the sense in which I defined it in 1904 (Science, N. S., vol. 19, p. 24)—for a series of strata about 500 feet thick, lying between the typical Chemung and the Waverly group (as limited below by the Berea sandstone), and comprising in the typical sections near Bradford, Pa., and Olean, N. Y., the formations described under the names of Cattaraugus, Oswayo and Knapp.

Some diversity of opinion exists as to the principles which should govern the interpretation of paleontological evidence in determining the boundaries of geologic systems. I propose to consider these different views and to decide which is to be employed in the present investigation. Thus, to take a put case, it is sometimes said that the line between the Devonian and the Carboniferous should be placed at the first introduction of Carboniferous species. This principle seems by implication or otherwise to be adopted by Glenn and Butts and Clarke in their discussion of the geology of the Olean quadrangle and other areas in western New York.[6] It is true that, in adopting this principle in the Olean rock section, the authors were influenced by the belief that the interval below the Olean conglomerate member of the Pottsville formation in the Olean quadrangle corresponded to the interval similarly underlying the Olean conglomerate in northwestern Pennsylvania and northeastern Ohio, so that several hundred feet in the one section would have to correspond to the authentic Waverly group in the other.[7] Now that it is known, or at least seems highly probable, that, owing to erosion which preceded the Olean conglomerate, that member rests on lower and lower strata as it is followed eastward, so that at Warren, Pa., most of the Waverly rocks are missing and they are not known to appear in the sections farther east,—with this condition of affairs granted, it is possible that the authors would not have adopted the principle of first appearance. It is necessary, however, to examine this principle to see whether it is generally applicable or applicable to the present case.

The meaning of the principle as stated above is clearer at first sight than when it is examined more closely. The implication largely turns on the meaning which is given to the terms "Devonian" and "Carboniferous" species, and, at the risk of drifting into something like the Greek dialectic, it will not be unprofitable to consider this question. By Carboniferous species may be meant (*a*) any species which has been found in rocks of Carboniferous age; (*b*) a species especially abundant or widely spread and persistent in rocks of that age though occurring elsewhere, or (*c*) a species known only from the Carboniferous, or at least known there but not in the other geologic system with which comparison is made.

It is evident that, in the present instance, the words "Carboniferous

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[6] New York State Mus. Rept., vol. 56, pt. 2, 1903, pp. 985, 991 and 999. Clarke gave a somewhat more extended discussion the year previous (*idem*, vol. 55, 1902, p. 524) in which he showed that a marked faunal change took place at the base of the "Bradfordian," but not that the "Bradfordian" fauna had a preponderating Carboniferous aspect.

[7] *Loc. cit.*, p. 991.

species" cannot be taken with the first meaning (*a*), because some types found in the Carboniferous have a very long range and originated at much lower horizons. *Leptæna rhomboidalis* is an example.[8]

If we assume the second meaning (*b*) for the expression "Carboniferous species," the principle would mean frankly a redetermination of the Devonian-Carboniferous boundary, not only in other areas but in the typical area as well, a redetermination, moreover, which would never cease, because the Devonian beds which would thus be added to the Carboniferous would carry over other species having a sporadic appearance at lower horizons. This would entail a new adjustment and so on apparently until the bottom of the stratigraphic column was reached. Furthermore, is it one such species, or two, or a score that the application of this principle involves? Reasonably but one. The decision might easily then come to depend on the identification of one or two specimens resembling several closely related species.

If we now take the last meaning (*c*) for the expression "Carboniferous species," *i. e.*, species characteristic of the Carboniferous, those not known to occur at any horizon outside of the Carboniferous, the statement under consideration becomes hardly more than a truism, but a truism which assumes that we have complete knowledge of the range of species, that the species in question are not only not known to range outside of the Carboniferous but that they cannot so range, and this is an assumption which everyone knows is quite inadmissible, since the range of species as recognized at any time is continually being changed by new data. Other considerations might be brought forward, but it is already plain that this is not a workable principle, no matter how understood, for determining the boundaries between systems, or for classifying the Bedford shale.

It might be held, on the other hand, that the proper way to fix the line between the Devonian and Carboniferous systems is by the disappearance of the last Devonian forms. This principle is the antithesis of that just considered. It is open to the same objections and is equally untenable.

The only practicable method of interpreting paleontologic data in most cases of this sort is evidently by taking the balance of evidence. By this method the decision hangs not upon one or two forms but upon the entire number known, and, although the evidence of each form may be impaired by poor material and close relationship between species, it becomes cumulative. Here the expressions "Carboniferous" and "Devonian" species signify species especially common in their respective sys-

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[8] De Koninck, however, distinguishes the Mississippian Leptæna as a distinct species under the name *Leptæna analoga*.

tems. If the species are absolutely unknown outside of their respective systems, the evidence is so much the stronger, but the difference is one of degree only, and no assumption is made that a species at present known in the Carboniferous may not subsequently be found in the Devonian or *vice versa.* That a species has not yet been found in the other system, however, rightly gives it exceptional weight especially in regions where the available data on range are considerable.

This principle is of course unsatisfactory. It is impossible to estimate or to state the results mathematically. Different species have different values, and the same species may have different values in different regions. While these values are not expressible in numerical terms and indeed must vary somewhat with each observer according to the character and extent of his experience, nevertheless, in practice, the evidence is seldom so nicely balanced or the antecedent experience of those who judge it so diverse that reasonably satisfactory and unanimous conclusions are impossible.

In determining the relationship of geologic formations, which includes also the determination of their geologic age, some species have, as already pointed out, greater importance than others. This is partly because we know more about some than others. The determination of such relationships as I have mentioned rests very largely on our knowledge of the range in geologic time of different types of fossils and involves one of the most fallible of all processes of inductive reasoning. Because a fossil has not yet been found above or below a certain horizon it does not follow that it never will be so found, yet that is virtually the inference on which all correlations and age determinations are based. At best, this furnishes conclusions which are fairly safe, and at worst it furnishes conclusions which are highly unsafe. At its best, the conclusion depends upon the concurrence of a large number of species and upon species whose range has been ascertained by a large number of observations. For the same reason, it is clear that common species are more significant than rarer ones, because our knowledge about their range is more trustworthy, and, in some cases, fairly sound inferences can be drawn from a single species.

It is, however, not only the trustworthiness of our knowledge which lends greater significance to some forms than to others, but also the length of range in geologic time, which differs with almost every form; for, obviously the presence of a form which had an established range of 100 feet would be much more significant in correlation than that of one whose range was 1000 feet. Here enters also the consideration of groups larger and smaller than species, the range of which is, generally speaking, in proportion to their size,—long as the biologic rank of the group increases, short as the biologic rank of the group decreases.

Our knowledge of the range of fossils is conditioned by other things than the amount of data as to their occurrence, since it manifestly involves the identification of the fossil as a species and the identification of its geologic horizon. Another factor then which makes some forms more significant than others is that their generic and specific relations can be determined with greater certainty. Variation in this particular is in some cases intrinsic, in others extrinsic; often it depends upon both factors. Manifestly, in groups where variation is restricted in degree, or is restricted to a few characters, or is marked by complete intergradation, discrimination of species and even of genera is more difficult than others. Types which vary in shape alone have in my experience proved especially unsatisfactory, while those which are sculptured or which possess other features of relief give more reliable results, especially when, as is almost always the case, this is combined with variation in configuration also. Preservation, which in fossils has always destroyed the soft parts and the coloration, often obscures other characters too, and this deterioration, owing to peculiarities inherent in whole groups of shells, is more liable to befall some types than others. As is well known, owing to their physical rather than their chemical structure, the shells of pelecypods and cephalopods are apt to be removed by solution so that in Paleozoic rocks they are as a rule reduced to the condition of molds, while the shells of brachiopods retain their original composition. Also, partly because of the solution of the shell, which tends to obscure both sculptural or specific and structural or generic characters, partly because of being marked by growth lines alone and having the generic characters largely developed along the hinge where they are at best difficult of observation, many types of pelecypods show differences only in shape and configuration (which are peculiarly liable to be altered by compression), while at the same time quite widely different genera are in general aspect, which is about all that can be determined, very similar,—for these reasons pelecypods often prove an unsatisfactory group for stratigraphic paleontology, since even the generic position of specimens as they ordinarily occur in the Paleozoic is often undeterminable except on characters which are not of themselves strictly generic, although they are, or appear to be, correlated with generic characters.

It is obvious that, while the larger zoölogic groups are as a rule of less value because of their longer range, they are at the same time usually of greater value because of the precision and certainty with which they can be distinguished, for it hardly needs to be stated that a specimen can often be referred to a genus with certainty while its specific position is a matter of doubt. On the other hand, a provisional specific identification is sometimes only possible on the assumption of a generic one. Though because of their more extended range (in part compensated by the certainty of delimitation), the larger groups are less serviceable in correlating different sections, they are more instead of less valuable in estimating the importance of faunal changes in the same section, since they indicate a greater degree of change and possess the added advantage of increased certainty of discrimination.

Of equal importance with identification of a form in its biologic relations is the identification of its geologic horizon and this is frequently unsatisfactory. It seems to be true, and it is natural that it should be so, that in geologic time, as at the present day, the progress of sedimentation and the course of biologic development varied in different areas or provinces, and that deposits may be, so far as one can tell, essentially contemporaneous, and yet very different in lithologic character and in the character of their fauna and flora. The limits of geologic provinces are not clearly defined, if indeed it is not ultimately shown that they are without definite limits but are continuous with one another; and still less is it known what were the factors which produced their differentiation. For my own part, I have very little faith in the theory of barriers (in the sense of land barriers) as a panacea for all the ills of stratigraphic geology. On the contrary, I believe that during geologic time, as today, the conditions controlling the character and distribution of faunas are depth, temperature, food supply, current action, salinity, bottom and so forth. At all events, as between different provinces, most correlations are at present more or less provisional, so that while the paleontologist must not disregard the data from any area, his deductions concerning one province should be largely guided by the data from that province.

Since the data of range and distribution of species are in large measure not on record even when they have been ascertained, and since the records are very scattered, each investigator must approach a problem with a different store of facts on which to base his inference as to geologic age and correlation, but it by no means need follow that such partial or even one-sided knowledge must lead in different cases to different conclusions.

A number of years ago when much engaged with the investigation of these “Bradfordian” beds, from which I have since been temporarily diverted, I began and all but completed a descriptive study of the fauna of the “Corry” sandstone (since correlated with the Berea sandstone).

This fauna I will now list in the terms in which it was then prepared, as follows:

Crania levis Keyes
Rhipidomella n. sp.
Schuchertella desiderata Hall and Clarke
Productella n. sp.
Productus n. sp.
——— idem, n. var.
——— idem, n. var.
——— n. sp.
——— *arcuatus* Hall ?
——— *levicosta* n. var.
Strophalosia-like form, n. gen. n. sp.
Spirifer marionensis Shumard
——— *disjunctus* Sowerby ?
Cyrtina triplicata Simpson
Syringothyris angulata Simpson
——— *extenuata* Hall
Athyris lamellosa L'Éveillée
Cliothyridina squamosa n. var.
Camarotœchia heteropsis Winchell
Camarotœchia metallica White ?
Paraphorhynchus striatum Simpson
——— *mediale* Simpson
Pterinopecten alternatus Simpson
Aviculipecten equalatus Simpson ?
——— *patulus* Hall ?
——— *cancellatus* Hall ?
Paleoneilo sp.
Sphenotus sp.
Sanguinolites senilis Herrick
Spathella ? sp.
Cypricardinia sp.
Mytilarca sp.
Edmondia ? sp.
Straparollus roberti White ?
Platyceras varians Simpson
——— *dorsale* Simpson
Tropidodiscus crytolites Hall
Conularia byblis White ?

If this list is compared with the one which I shall give farther on, it will be seen how very different the "Corry" fauna is from the fauna of the Bedford shale. Thus the statement that a pronounced faunal change marks the transition from Bedford to Berea time seems amply justified. The second point which I wish to make in this connection is that, for the first time in this region, in the ascending series, we have a fauna of distinctly Carboniferous type. The "Corry" fauna contains much that is new, but the development of species of the *Productus* rather than the *Productella* group (though on this I do not lay much stress because of the difficulty of adequately determining one group from the other), and especially of a *Productus* of the *cora* type, an abundant *Spirifer* of the *marionensis* type, *Athyris lamellosa*, a species of *Cliothyridina*, two species of the Kinderhook genus *Paraphorhynchus* and a few other forms, identify this horizon as Carboniferous and probably Kinderhook. There is, to be sure, some evidence pointing the other way, as for instance a *Spirifer* doubtfully identified with *S. disjunctus* and the two Aviculipectens, also doubtfully referred to Devonian species, but no one will question on which side the evidence is stronger.

The fauna of the Bedford shale has never been described in full. Incomplete faunal lists have been given in two or three instances. A few species identified or figured from this formation may be found scattered among Hall's paleontological monographs (as *Macrodon hamiltoniæ*) and an occasional species has been described by other writers (as *Paleoneilo bedfordensis* by Meek). Herrick[9] has published a plate of figures drawn from specimens obtained at Central College in the central part of the State, and Foerste[10] has described and figured a very limited development of the fauna as represented in eastern Kentucky. It may be said, however, that the Bedford fauna is very imperfectly known.

In my work on the "Bradfordian," the fauna of the Bedford shale was collected and in part described. As represented in my collections, the Bedford fauna in the typical localities of Cuyahoga County, Ohio, comprises about 50 species, which may be listed as follows:

Lingula n. sp.
——— *irvinensis* Foerste ?
Lingulidiscina n. sp.
——— *newberryi* Hall ?
Pholidops n. sp.
Schuchertella herricki Foerste
Chonetes n. sp.
Productella pyxidata n. var.
Strophalosia sp.
Rhipidomella n. sp.
Cranæna ? aff. *subelliptica* Hall and Clarke
Cryptonella ? sp.
Camarotœchia sappho Hall
Delthyris n. sp., aff. *sculptilis* Hall and *missouriensis* Weller
Spirifer aff. *marionensis* Shumard ?
Syringothyris carteri Hall
Nucleospira ? sp.
Camarospira ? sp.
Athyris aff. *hannibalensis* Swallow and *fultonensis* Swallow
Paleoneilo bedfordensis Meek.
Leda diversa Hall
Solenopsis ? sp.
Pterinopecten ? n. sp.
Macrodon hamiltoniæ Hall
Edmondia aff. *subovata* Hall and *ellipsis* Hall
Cypricardella aff. *gregaria* Hall and *tenuistriata* Hall
Sphenotus aff. *cuneatus* Conrad and *contractus* Hall
Pholadella newberryi Hall ?
——— sp.
Ptychodesma ? sp.
Bellerophon aff. *pelops* Hall, *mæra* Hall and *jeffersonensis* Weller
Tropidodiscus aff. *acutilira* Hall, *brevilineatus* Conrad and *cyrtolites* Hall
Pleurotomaria aff. *sulcimarginata* Conrad
Platyceras sp.
Loxonema ? sp.
Conularia aff. *newberryi* Winchell
Hyolithes sp.
Orthoceras sp.
Goniatites sp.
Proëtus ? sp.

In addition, there is a doubtful species of *Rhombopora*, several species of conodonts, which are rare, and abundant though ill-preserved ostracods suggesting the genera *Primitia*, *Cytherella*, *Beyrichia* (2 species) and *Paraparchites*.

The identifications and comparisons given above are subject to revision, but, in spite of such possible changes, the list will serve to show

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[9] Sci. Lab. Denison Univ., Bull., vol. 4, pl. IX.
[10] Ohio Nat., vol. 9, p. 515 et seq. 1909.

the general character of the typical Bedford fauna as represented in very complete collections.

Before commenting on the characters of this fauna, as shown by my list, it will be desirable to consider some species which have been recorded from the Bedford and which I have not identified there.

Newberry has cited the following species from the Bedford shale:

Syringothyris typa Win.
Orthis michelini Lev.
Spiriferina solidirostris White
Macrodon hamiltoniæ Hall
Hemipronites crenistria Phil.
Chonetes logani Hall
Lingula cuyahoga Hall
Rhynchonella sagerana Win.

upon which he comments in these words:

> "In this list there are several which have peculiar interest and significance, *Syringothyris typa* and *Spiriferina solidirostris*, for example, from the fact that they are characteristic of the Lower Carboniferous rocks of other States, while *Orthis michelini* is common to the Carboniferous formation all over our country and in Europe."

Herrick,[11] referring I doubt not to this passage, says:

> "Dr. Newberry has decided that the Bedford shale is Carboniferous on the basis of such fossils as *Syringothyris typa*, *Hemipronites crenistria*, *Chonetes logani*, *Orthis michelina* and *Spiriferina solidirostris* and a few more. Having searched in the same localities without finding these forms in the typical Bedford as it appears in southern Ohio and on the other hand finding the species above mentioned [in a preceding list] we feel some hesitation as to the occasion of the confusion. These species may indeed occur below the Berea, but in flags and greyish shales *not in the blue or red Bedford shale!*"

As to the closing remark I may say that though Newberry did not describe or figure the species which he named, there is, owing to the constitution of the Bedford fauna, no reasonable doubt as to what types he wished to indicate in each case, and Herrick is quite in error in supposing that these species did not come from the true Bedford shale.

Now, as to the species mentioned by Herrick, *Orthis michelina* and *Hemipronites crenistria* are the species which I have listed as *Schuchertella herricki* and *Rhipidomella* n. sp. The difficulty of discriminating species among the Rhipidomellas and Schuchertellas is such that these types are of minor importance in correlating faunas. The Waverly Schuchertellas are so closely allied to *S. chemungensis* that it would demand considerable temerity to say that a given suite of fossils belonged to a species of the one fauna rather than to a species of the other and indicated either Carboniferous or Devonian age. Much the same is true

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[11] *Op. cit.*, p. 109.

of the Rhipidomellas, but if reliance may be placed on the size and shape of the muscle scars, which are usually regarded as good specific characters in this group, I may say positively that the Bedford form is not *Rhipidomella burlingtonensis* (which was described as a variety of *michelini* and is the most probable species indicated by that name which was originally applied to a European form). *Chonetes logani* is the form which I called *Chonetes* n. sp., and which was beyond question wrongly identified with Norwood and Pratten's species. For *Syringothyris typa,* I have adopted Schuchert's identification, *S. carteri.* When Newberry wrote, and when Herrick wrote for that matter, the genus *Syringothyris* was regarded as a diagnostic Carboniferous type and very justly, so far as the facts were then known, but it has subsequently been found that the genus occurs abundantly in direct association with *Spirifer disjunctus* in the "Bradfordian" rocks of northwestern Pennsylvania. Since *S. disjunctus* has always been regarded as being as emphatic a marker of the Devonian as *Syringothyris* was of the Carboniferous, it is clear that the evidence of either type is disqualified for deciding the question at issue. Schuchert[12] has even described a species of *Syringothyris* from the middle Devonian of Missouri, and furthermore a tendency to develop the syrinx seems to be manifested in several Devonian species of *Spirifer,* so that it would seem as if the evidence of *S. disjunctus* should be esteemed of greater weight in favor of the Devonian than that of *Syringothyris* in favor of the Carboniferous age of the "Bradfordian" strata.

Newberry's *Spiriferina solidirostris* is the *Delthyris* n. sp. of my list. It is absolutely certain that this form is not the Kinderhook species *S. solidirostris* and almost equally certain that it is not a *Spiriferina* at all. It has, it is true, the general expression and the median septum which are found in *Spiriferina* and which are also found in the group of Spirifers to which the title *Delthyris* has been applied, but it does not possess the punctate shell structure which is an indispensable character of *Spiriferina.* The form in question is not rare in the Bedford shale and I have been able to examine a considerable number of specimens. This I have done both with a hand lens and with a compound microscope without success in finding the punctate structure which is usually a feature easily detected in species really belonging to the genus. Thus, I am forced to conclude that the form is not a *Spiriferina,* which is a typical Carboniferous genus, but that it is a *Delthyris,* which is an almost equally typical Devonian one.

I have thus traversed all the forms thought by Newberry or by Herrick to indicate a Carboniferous age for the Bedford fauna, and their

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[12] Am. Jour. Sci., vol. 30, p. 223. 1910.

supposed significance has for one reason or another quite disappeared under impartial criticism.

Consideration seems to be demanded at this point of a small list of "Carboniferous" species cited by Mr. Butts from the "Bradfordian" of the Olean quadrangle. These species are not known in the Bedford shale, but the Bedford interval is probably represented in the Olean section, though not distinctly recognizable there. At all events, if the Knapp and Oswayo formations of the Olean section are Carboniferous, it is clear that the Bedford shale must be Carboniferous, whatever its fauna, since if it does not represent some horizon in those formations, it must represent one above, rather than below them. It is therefore germane to this discussion to scrutinize the evidence for calling the Knapp and Oswayo formations Carboniferous. I suspect that the authors of the work in which these species are cited would have proceeded differently if they had not assumed as a postulate the general equivalence of the Olean rock section with that of northwestern Pennsylvania and northeastern Ohio, so that the question which they considered was not, "Is the Carboniferous actually represented in the Olean section?" but, "Since the Carboniferous is represented in the Olean section, where should the line best be drawn between it and the Devonian?"[13]

The "Carboniferous" types cited by Mr. Butts make up a total of but seven out of a list of 59 species. All the rest are Devonian forms, most of which, and possibly all, have never been found in rocks of Carboniferous age, so that were we to consider the question whether the faunas show a predominating Devonian or Carboniferous facies, there could be but one answer. It is only by adhering to the rule of "first appearance" that these formations can with any justification be called Carboniferous.

Let us, however, consider the Carboniferous character of the seven species on which this age determination depends. In addition to two fishes referred to the Carboniferous genera *Ctenodus* and *Gyracanthus*, the list includes five invertebrates. These are *Oehlertella pleurites*, *Orthothetes crenistria*, *Glossites* (*Sanguinolites*) *amygdalinus* ?, *Sphenotus æolus* ?, *Crenipecten winchelli.*

I have already expressed the opinion that but little reliance can be placed upon the Schuchertellas in matters of correlation because of the difficulties of drawing any satisfactory lines between species or supposed species in the genus. The significance in the present instance is still

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[13] This reference of the Knapp and Oswayo formations to the Carboniferous has recently been reaffirmed by Hartnagel (New York State Museum, Handbook 19, p. 87 et seq., April 1912), without the discussion that would seem to be demanded by the subsequently known fact that these formations occur below the Waverly group of Ohio (at least if the Berea sandstone is taken as the base).

farther reduced by the fact that *Schuchertella* (*Orthothetes*) *crenistria* is a strictly European species, though the name has been applied to several forms in the Waverly which might be regarded as a single species or split up on rather small differences into several, according to the disposition of the investigator, and of which some are doubtfully distinct even on trivial characters from the common Chemung form *Schuchertella chemungensis.*

From my own experience if any brachiopods are less satisfactory for identification and therefore for correlation than the Schuchertellas, they are the Discinoids, to which *Oehlertella pleurites* belongs. On the whole, however, this species, which is a rather common "Bradfordian" type, must be regarded as Carboniferous rather than Devonian in its bearing.

The Pectinoids are greatly diversified in shape and especially in external ornament, and a number of fairly distinct groups can be made on superficial characters, some groups small and peculiar, others more comman and generalized. To the commonest and most general of these, *Crenipecten winchelli* belongs. Now species superficially very similar to this are found in other genera, such as *Pecten, Aviculipecten, Deltopecten,* so that, as the hinge characters are very seldom to be observed, it is usually impossible to determine with certainty the generic group to which these commonplace Pectens belong, and this fact naturally brings into doubt the specific identification even when the superficial resemblance is close. The identification in this case is made without a query, however, and *Crenipecten winchelli* must be regarded as a distinctly Carboniferous type.

Glossites amygdalinus and *Sphenotus æolus* are also distinctly Carboniferous species, but in their case the identification is admittedly doubtful.

I have not consciously made little of the evidence presented by Mr. Butts, yet two of the species in his list are obviously identified with doubt and it seems to me that of the remaining five the three invertebrates and possibly also the two fishes belong to types in which the discrimination of species is difficult and unsatisfactory even with very good material. Furthermore, in interpreting the evidence I would think it wiser to extend the range downward of seven species rather than extend the range upward of 52.

In seeking to determine whether the Bedford shale should be classed as Devonian or Carboniferous, the problem is not perhaps whether it carries a Chemung or a Kinderhook fauna; it is not a mere matter of correlation, though correlation is involved. The fact seems to be that the Bedford shale represents part of an interval between the base of the Mississippian and the top of the Devonian as those systems have usually been defined and the real question is whether as such, from all the evidence at hand, it belongs more properly with the one system or with the other.

The base of the Carboniferous system in this country, as usually recognized, is the Kinderhook group of the Mississippi Valley; similarly the top of the Devonian system is the Chemung group of New York. Now, there is substantial evidence for believing that the Berea sandstone represents about the horizon of the Kinderhook and that it occurs several hundred feet above the top of the true Chemung. The evidence for this may be briefly summarized as follows: The representative of the Berea in Crawford and Erie counties in northwestern Pennsylvania appears to be the "Corry" sandstone. The "Corry" is more fossiliferous than the Berea and contains a varied and characteristic fauna. The "Corry" horizon carrying this fauna can be traced eastward to Cobhams Hill just east of Warren, where it comes in immediately above what has been called the "sub-Olean conglomerate" (Knapp formation), in the short interval which separates that formation and the Olean conglomerate. Beyond this the "Corry" horizon cannot be recognized, but it seems to be a matter of common agreement[14] that the "sub-Olean conglomerate" at Warren and the beds beneath represent the formations which in the Olean quadrangle come in below the Olean conglomerate, where an interval of about 500 feet, comprising the Oswayo and Cattaraugus formations, occurs above the typical Chemung. Similar facts are indicated by I. C. White's work in Crawford and Erie counties,[15] since he recognizes the Venango oil sand group (which he calls Upper Chemung), with a thickness of 310 feet, and the Riceville shale with a thickness of 80 feet as intervening between the Chemung proper and the formations for which he used the names Corry and Cussewago. However many errors in detail there may be in these tracings and correlations, it seems safe to conclude that an interval of 400 or 500 feet does intervene between the top of the true Chemung and the "Corry" (Berea) sandstone in this area, which is probably represented in Ohio by the Bedford, Cleveland and Chagrin formations.

The first point to be considered in the paleontologic aspect of the problem is the affinity of the Bedford fauna, its predominant Devonian or Carboniferous facies interpreted on the facts of the general region in which the Bedford shale and the Bedford fauna were developed.

Many genera and a few species, after a greater or less development in the Devonian, pass upward into the Carboniferous, ranging to various horizons in the Mississippian or even above. In most cases, there is no

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[14] See the report by Glenn, Butts and Clarke already cited.

[15] Sec. Geol. Surv. Pennsylvania, Rept. Q. 4, 1881.

general character or characters by which the Carboniferous species as a whole differ from the Devonian species. In some instances, however, certain general types within a genus appear to be restricted to one system of rocks or the other. Thus, the *punctatus* group of *Producti* is a distinctly Carboniferous development of the genus so far as known. Now, the great bulk of the Bedford fauna, as will be seen from an examination of the table given on another page, belongs to types not characteristic of either system. Most of them would not appear out of place in either a distinctly Devonian or a distinctly Carboniferous fauna. In such an association, one might say "This is a new species in this fauna" but not "This is a Devonian species" or "a Carboniferous species," as the case might be. Thus most of the Bedford species, considered in their broader relations, are ambiguous in deciding the Devonian or Carboniferous affinities of an intermediate fauna. One might indeed take up the Bedford fauna species by species and draw an inference from the number of Devonian, of Carboniferous and of new species as to whether the fauna should be grouped with the Devonian below or with the Carboniferous above. Such a careful canvass of the relationship of the different Bedford species would require more time than it has been possible for me to give and would almost need be accompanied by a discussion of each species, such as would be out of place in a paper of the present scope. Besides this, as between closely related species in the Devonian and the Carboniferous the conclusion reached in the identification would many times be a matter of personal opinion. Comparisons sufficiently ample have been made, however, to show that many of the Bedford species are new and that the Carboniferous alliances are at least not more numerous than the Devonian. I propose, on the other hand, to point out a few instances of larger groups than species, about the identification of which there can be less room for personal differences of opinion and which, because they do represent larger groups, carry more weight than species themselves, for I take it that the horizon which marked the extinction of the genus *Spirifer* would be more noteworthy than that which marked the extinction of some one species of *Spirifer*, such as *S. keokuk*. Of such peculiarly pre-Carboniferous types, the first in my list is the genus *Pholidops*, which has never the world over I believe been found at horizons recognized as Carboniferous. The next on the list is *Delthyris*, which has usually been identified in the Bedford fauna as *Spiriferina* and which I have already discussed at some length. This is a distinctly Devonian type of *Spirifer* and with one or two exceptions, to which reference will be made later, has never been cited from Carboniferous rocks. Next come the types which I have called *Nucleospira* ? sp. and *Camarospira* ? sp.

These two forms present serious difficulties of exact identification, being complicated with each other and with the two terebratuloids which I have called *Cranæna* aff. *subelliptica* and *Cryptonella* ? sp. These are among the rarer forms of the Bedford fauna. When preserved in the shale they are apt to be badly crushed, but they often retain the shell, so that its structure can be determined. When preserved in the calcareous nodules, the shell is not retained (or its structure is obscured), but the proportions are not seriously altered. Thus, among these poorly characterized, generally ovate forms there are clearly two types, one with a punctate and one with a fibrous shell and of each type there appear to be two species, distinguished more or less strongly by size and configuration. Where the specimens have their real characters obscured by crushing or in other ways (and this is true of many of them) they cannot be satisfactorily placed in this scheme. The shells with fibrous structure have the general appearance of Athyroids, and for such they might casually be mistaken, but the ventral valve (and in one type both valves) is furnished with a well-developed median septum. This character is not only alien to the Athyroids, such as *Composita* which the configuration suggests, but I do not know of any Carboniferous genus which has at once this shape and this structure. The larger of the two species suggests *Camarospira* more than any other genus with which I am acquainted, and the smaller more transverse one, which has a dorsal as well as a ventral septum, is certainly very suggestive of *Nucleospira*. I have even observed what appear to be traces of fine setæ on external molds.

It cannot be positively asserted that these forms belong to the genera named, but it is true so far as I am aware that no genera having the character of these Bedford shells are known in any Carboniferous rocks of the Appalachian region. A few occurrences of *Delthyris* and *Nucleospira* have been noted in the Kinderhook group of the Mississippi Valley, but aside from this the *Pholidops*, the *Delthyris*, the *Nucleospira* ? and the *Camarospira* ? are peculiarly Devonian types and are not found in the Carboniferous.

On the other or Carboniferous side must be mentioned the *Syringothyris*, which can, however, no longer be regarded as distinctly Carboniferous in its generic range. The Bedford form is, however, identified with a Carboniferous species. Again, I have a single very poor *Spirifer* which seems to belong to the *marionensis* group (a Carboniferous type), but which may be a somewhat abnormal *S. disjunctus* (a Devonian type). Lastly there is a species of *Pholadella* which is more nearly allied to the Carboniferous *P. newberryi* than to the Devonian *P. radiata*. These Carboniferous affinities, it will be noted, are specific, while the Devonian ones are generic.

To summarize the matter so far as considered, the Bedford fauna is in many respects unique. It can be traced southward into Kentucky, but it cannot be traced eastward into Pennsylvania. Its place in the "Bradfordian" of Pennsylvania has not been determined. It is distinct from the "Bradfordian" fauna. It is distinct from the Chemung fauna. It is quite distinct from the Chagrin fauna, which underlies it in the same section, and which, while differing in important particulars from the typical Chemung fauna, has nevertheless more of a Chemung aspect. It is equally distinct from the overlying Berea ("Corry") fauna, which has more of a Mississippian aspect. It has a Devonian, or, as has sometimes been said, a Hamilton facies, because, while it consists mostly of genera which range into the Carboniferous and of species many of which have Carboniferous affinities, it is nearly lacking in the strictly Carboniferous types which abundantly accompany the latter at higher horizons and proclaim the geologic age, and because it contains a few Devonian types which very rarely and in the region under consideration never, so far as known, range up into the Carboniferous.

The Bedford and Cleveland formations may be lacking in northwestern Pennsylvania owing to pre-Berea erosion, or to some other cause, but I hardly believe this to be the case. If the Bedford does represent part of the typical "Bradfordian" section, and if its fauna is a peculiar and local development of the "Bradfordian fauna," then we must enlarge the discussion to include the "Bradfordian" ("Upper Chemung") faunas, whose Devonian facies is conspicuous.[16] In the one case (if properly lying above the "Bradfordian" but removed by erosion in the typical section) the stratigraphic evidence, and in the other the paleontologic evidence, is stronger for classifying the Bedford shale as Devonian. To this must also be added the fact of a conspicuous faunal break between the Bedford and the Berea, and the fact already noted that in the Berea ("Corry") we have, for the first time in this region, a fauna with a predominating Carboniferous aspect, one which shows many new features when compared with the typical Mississippian, but which is distinguished by the absence of most of the Devonian types of lower horizons and the presence of many characteristic Carboniferous ones.

Thus far it seems that the evidence has been strongly favorable to classifying the Bedford with the Devonian. If we broaden the discussion so as to include a larger field, that of the typical Mississippian area, which apparently represents a conspicuously different province, or at

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[16] See the "Upper Chemung" species of Hall's New York reports and Butts's lists of the faunas of the Knapp and Oswayo formations. These show a fauna with well marked differences from the typical Chemung, yet with, in my opinion, a distinctly Devonian aspect.

least represents a conspicuously different faunal development, the question becomes more confusing and the conclusion somewhat less satisfactory.

A search among the American faunas now known for one which is comparable with that of the Bedford shale probably reveals none so similar in a general way as a certain phase of the Kinderhook developed at Hamburg, Illinois, and the closely related one developed in the Glen Park limestone member of the Kinderhook of Missouri. The constitution of these faunas, generically considered, is surprisingly close and many of the species seem to be related. These may be arranged in parallel columns, as follows:

Bedford shale	Limestones of the Kinderhook at Glen Park, Louisiana or Hamburg
Schuchertella herricki	*Schuchertella chemungensis*
Productella pyxidata var. *bedfordensis*	*Productella pyxidata*
Rhipidomella n. sp.	*Rhipidomella missouriensis*
Cryptonella ? sp.	*Cryptonella* sp.
Delthyris n. sp.	*Delthyris missouriensis*
Syringothyris carteri	*Syringothyris carteri*
Spirifer aff. *marionensis* ?	*Spirifer marionensis*
Athyris aff. *hannibalensis*	*Athyris hannibalensis*
Macrodon hamiltoniæ	*Macrodon sulcatus*
Leda diversa	*Leda diversoides*
Bellerophon aff. *jeffersonensis*	*Bellerophon jeffersonensis*
Platyceras sp.	*Platyceras erectoides*
Tropidodiscus cyrtolites ?	*Tropidodiscus cyrtolites*

There is also a *Chonetes* in both faunas, though of not very close relationship; a *Camarotœchia*, though the Bedford form is large and the Hamburg form small; and a *Nucleospira*, though also specifically distinct. In fact, while many of the same genera are present in both areas, there are very few species which are really identical, and those for the most part belong to genera in which the identification of species is difficult and a satisfactory identification impossible. *Syringothyris carteri* is an example.

Professor Weller[17] has pointed out the close relationship which exists between the Kinderhook fauna at Glen Park, Missouri, and that from the oölitic beds at Hamburg, Illinois, and he has also called attention to the conspicuous Devonian facies which these faunas present (p. 463), a resemblance which (like that of the Bedford) would seem to ally them with the Hamilton rather than with the later Devonian faunas. Professor Weller finds that 12 out of the 31 species at present known from

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[17] Acad. Sci. St. Louis, Trans., vol. 16, p. 462 et seq. 1906.

Glen Park can be paralleled in the Hamilton formation of New York, while only six species have parallel forms in the Chouteau limestone of Missouri. Although the Chouteau fauna is so near at hand, he is able to find specific identity in only two species and those are *Schuchertella chemungensis* and *Tropidodiscus cyrtolites.* When we consider this fact and that the fauna comprises such Devonian genera as *Eunella, Atrypa, Nucleospira* and *Delthyris,* not to mention the fish *Ptyctodus eastmani,* it would seem that the Devonian proclivities of the fauna far outweigh the Carboniferous ones, even with due consideration for the two doubtfully identified crinoid genera. This evidence is largely neutralized, however, when other factors are taken into consideration.

The Kinderhook faunas of the upper Mississippi Valley show local facies to an almost unprecedented degree. To some extent, this differentiation may have a zonal explanation, but it is also probably local and environmental, since the lithologic character of the beds is also extremely variable. Professor Weller recognizes a northern and southern type of Kinderhook fauna which were contemporaneous, but almost entirely different. The Chouteau limestone exemplifies the southern fauna and with this, as just noted, the Glen Park fauna has only two species in common, although Professor Weller apparently regards them as occupying the same horizon. Both the northern and the southern faunas are also highly diversified.

Beneath the fauna of the oölite at Hamburg, referred to above, which so closely resembles that of the Glen Park limestone, there is another having a considerably different facies. The latter Professor Weller correlates with the well-known fauna of the Louisiana limestone and this in turn with the typical Kinderhook of that ilk, which corresponds to the lower and larger portion of the Kinderhook section at Burlington. On the other hand, he correlates the fauna of the oölite at Hamburg with the Glen Park fauna and the Glen Park fauna with the Chouteau fauna, and with the upper part of the Kinderhook section at Burlington, if I understand him aright.

Several very different facies are presented by these faunas. That of the Louisiana limestone (at Louisiana, Missouri, and Hamburg, Illinois) is distinctly more Carboniferous than that of the oölitic limestone at Hamburg and Glen Park, which, as already noted, are rather conspicuously Devonian, though they occur above the other in stratigraphic position. The faunas of the Chouteau limestone and the topmost Kinderhook at Burlington, with which the faunas of the oölitic limestone at Glen Park and Hamburg appear to correlate, are still more conspicuously Carboniferous, and they have so been recognized for a long time.

As I have just shown, the fauna of the Bedford shale and the fauna of the oölitic limestone at Glen Park and at Hamburg are in some respects strikingly alike, but, though the resemblances are undoubted, there are also numerous and important differences. The resemblances consist of the presence in both faunas of identical genera and of related species. Identical species, however, are few and not of the first importance. The *Delthyris*, the *Nucleospira*, the *Macrodon*, etc., of the Bedford shale are not the same species as the *Delthyris*, the *Nucleospira*, the *Macrodon*, etc., of the oölite at Glen Park and at Hamburg. Correlation by similar species is certainly much more hazardous and less satisfactory than correlation by identical species. Indeed, although we of course know that all these faunas are more recent than the Hamilton, the table compiled by Professor Weller would indicate that the Glen Park fauna is almost as closely related to the Hamilton faunas as it is to that of the Bedford shale and much more closely related to the Hamilton than to the contemporaneous Chouteau fauna. Restricted to their own showing, therefore, I believe that a correlation of the Bedford and Glen Park faunas would not be justified, except in a very provisional and tentative manner.

However that may be, if, instead of considering the two faunas as isolated occurrences, we include, as we are forced to do, the faunas associated or correlated with them—the typical Kinderhook, the Chouteau and the Louisiana faunas of the Mississippi Valley in the one case, and the "Bradfordian" faunas of Pennsylvania in the other—it seems clear that we have two entirely distinct faunas, the one showing a strongly Carboniferous and the other a strongly Devonian facies, and we cannot conclude that they are contemporaneous expressions of the same faunal zone on any evidence now known.

The Bedford and Cleveland shales cannot be definitely identified in the "Bradfordian" rocks of northwestern Pennsylvania, either lithologically or paleontologically, but there is an interval between the Berea ("Corry") sandstone and the Venango oil sand group which seems to correspond in a general way to that represented in Ohio by these formations, and I personally but little doubt that Bedford and Cleveland do correspond to strata in the "Bradfordian." Even, however, if they do not, and the "Bradfordian" with its strongly Devonian fauna does entirely underlie the Bedford, I believe that the correlation of the Bedford shale with the oölites at Hamburg and Glen Park would not be justified at present.

The small number of identical species and the almost complete absence of all those characteristic Carboniferous types which by Professor Weller's correlations occur at the same horizon as the oölitic limestones at Glen Park and Hamburg or below, though not yet found associated with them, would, in the absence of substantial evidence to the contrary, indicate that the Bedford shale was not really a contemporaneous formation.

The correlation of other horizons in the same sections is intimately connected with that of the Bedford shale. Professor Weller[18] recognizes in the famous goniatite-bearing limestone at Rockford, Ind., a representative of the Chouteau limestone or southern Kinderhook. It is perhaps impossible to tell in fact, as it is certainly impossible to tell from his discussion, whether the limestone at Rockford corresponds to that part of the Chouteau which correlates with the northern Kinderhook or to that part which he recognizes in the Burlington section as occurring above the northern Kinderhook. If the Bedford represents the Glen Park horizon, it would apparently on the one hypothesis correlate with the goniatite-bearing bed at Rockford (and it does contain some goniatites of scarcely determinable genera), while on the other hypothesis it would come in above it. The position of the Bedford shale above the black Cleveland shale is at first suggestive of the position of the goniatite-bearing bed at Rockford above the Devonian black shale of Indiana, but there is no assurance whatsoever that the two black shales represent the same horizon and, even if such were shown to be true, it would not necessarily follow that the succeeding formation in the one case corresponded to the succeeding formation in the other. Indeed, until quite recently it has been the general consensus of opinion that the goniatite-bearing bed and the black shale beneath were quite separate and distinct formations divided by a long-time interval, the one of Carbonifrous, the other of Devonian age, and no satisfactory evidence has yet been produced for believing otherwise. On the other hand, such facts as I am acquainted with both of stratigraphy and paleontology go to show that the Bedford and Cleveland shales are related in the closest manner and must be classed together wherever they are classed.

The early Mississippian sections of Ohio and of the Mississippi Valley show great differences of development, both in the sediments which accumulated there and in the animal life which those sediments helped to condition. They probably constitute distinct provinces. There are no faunas in Ohio closely allied to the typical Burlington and Keokuk faunas,—nothing to correspond to the rich development of crinoid life which is found in those faunas and which doubtless did much to determine the character of the associated life, unless still different influences determined both. The 18 species of crinoids known from the Cuyahoga

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[18] *Loc. cit.*, p. 469.

shale, though belonging to genera well represented in the early Mississippian of the Mississippi Valley, do not occur outside the State. Anyone, however, who will compare the fauna of the Chouteau limestone with that of the Cuyahoga shale, as found at such points as Medina, Richfield, Lodi and Royalton, cannot fail to find great similarity and not a few identical species. I am not prepared to state the exact extent of this resemblance, but my studies would indicate strongly that, if the Cuyahoga fauna is to be found anywhere in the Mississippi Valley, it is to be found in the Chouteau limestone. The Waverly localities which I have mentioned are all, I believe, in the upper Cuyahoga. By definition, the Chouteau limestone is part of the Kinderhook group and therefore in stratigraphic position inferior to the Burlington limestone, but I am much disposed to think that the Chouteau limestone really correlates with the lower Burlington, the fauna which we know as the Burlington fauna being developed in and largely confined to the upper Burlington.

I have already given a list of the fossils found in the Berea ("Corry") sandstone which underlies the Cuyahoga shale. This fauna contrasts strongly with both the Bedford fauna below and the Cuyahoga fauna above. It has a much more marked Carboniferous aspect than the Bedford fauna, even if we exclude the faunas apparently contemporaneous with the Bedford having a more distinctly Devonian facies. Though, of course, showing great individuality, the "Corry" fauna is not only distinctly Carboniferous, but in some of its elements it is distinctly Kinderhook, as for instance in the genus *Paraphorhynchus*, a type which Professor Weller regards of special importance and which is said to be characteristic of the northern Kinderhook.

It is interesting to find three faunas in the Ohio section showing resemblances, more or less illusory perhaps, to these three aspects of the Kinderhook faunas of the Mississippi Valley, and it is also interesting to compare the stratigraphic relations of these faunas in the two areas on the assumption that the Cuyahoga shale correlates with the Chouteau limestone, the Berea sandstone with the northern Kinderhook (the *Chonopectus* fauna of the Kinderhook sections at Burlington), and the Bedford shale with the oölite at Glen Park or Hamburg, as is to some extent suggested by faunal similarities. According to their stratigraphic relationship in typical sections in the Mississippi Valley, the Bedford shale should not lie below the Berea sandstone, but above it. It should in fact even be contemporaneous with part, if not with all of the Cuyahoga shale. If, however, the Kinderhook relationship of the Bedford be eliminated, as I believe it can be eliminated owing to its probable relationship to other "Bradfordian" faunas, this contradiction largely disappears. The Cuyahoga and Berea together represent the Kinderhook of the Burlington section (in which, if I understand him aright, Professor Weller thinks that the upper 15 feet corresponds to the upper part of the Chouteau, both stratigraphially and faunally, while the lower part of the two sections corresponds stratigraphically but not faunally), and they have the same relative position in both sections. If my hypothesis of the equivalence of the Chouteau with the lower Burlington is correct, then of course the Berea alone represents the entire Kinderhook section at Burlington and presumably its correlates at Louisiana and at Hamburg with their varying faunas.

Professor Weller, as already described, recognizes two types of Kinderhook faunas, the northern one, the typical Kinderhook, not being found at all southward in southern Missouri and Arkansas; the other, the Chouteau, occurring in Arkansas and Missouri and represented by a few feet of rocks above the northern Kinderhook in the section at Burlington. Professor Weller's interpretation of these facts is that the two faunas were developed contemporaneously in disconnected basins, to the more northern of which the southern fauna gained access near the close of Kinderhook time. Tentatively, I would prefer to explain these relations by supposing that the southern Kinderhook was entirely later than the northern and was represented in the Burlington section not by the topmost Kinderhook alone, but by the lower Burlington also. However that may be, the disappearance southward of the northern Kinderhook fauna is somewhat suggestive of the southward thinning of the Bedford and the Berea formations, as recently described by W. C. Morse and A. F. Foerste.[19]

The careful stratigraphic work of these writers, combined with that of Professor Prosser, indicates that the Bedford and Berea gradually thin to a feather edge and presumably disappear as recognizable formations in east-central Kentucky. To some extent, they also lose their distinctive lithologic characters, so that Morse denominates as "Bedford-Berea" the interval of shale and sandstone which they fill between the black Ohio and Sunbury shales. The tracing by stratigraphy is corroborated by the occurrence of more or less characteristic Bedford fossils at the base of this interval in Kentucky, and Dr. Foerste himself very justly raises the question whether the final appearance of these sediments, which consist of shale alone, should not be referred solely to the Bedford formation, and the preceding occurrences in which the shales predominate below and the sandstone above should not be divided into Bedford and

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[19] Jour. Geol., vol. 17, p. 164 et seq. 1909.

Berea, respectively. In view of the fact that the Berea possesses a characteristic fauna which has not been found in the sections under consideration, whereas the Bedford fauna has been found there, and in a shale, and at the base of the interval, it seems to me that that portion of the interval would better be identified as Bedford alone, whatever is done with the upper part, though the evidence would suggest the advisability of calling the upper sandy beds Berea where they are present, and the whole interval Bedford where they are not.

The bearing which this aspect of the Bedford-Berea stratigraphy has on the question of the geologic age of the Bedford shale is not entirely clear. From one point of view, one might say that it did not affect the classification of the beds at all, except insofar as it made them difficult to distinguish in the field and to delineate on a map. On the other hand, it might be urged with some force that since by the expansion and differentiation of the Chattanooga shale in a northward direction, that formation seems to cover an interval including the lower Cuyahoga, the Berea, the Bedford, the Chagrin and probably the Huron formations, and in a manner to bind them together into one group of sediments, they ought all to be classed as Devonian or all as Carboniferous. This, however, does not at all agree with the facts, where these formations are differentiated and developed in an unequivocal manner, and I believe that it should not prejudice such a classification of the rocks as is indicated by the facts ascertainable under those conditions.

Therefore, while the weight of the evidence is not entirely cast on one side of the question, I believe that so far as the facts are known they indicate the line at the base of the Berea sandstone as the proper position of the Devonian-Carboniferous boundary in northern Ohio. This is because that boundary is marked by an unconformity, by the presence of a basal sandstone and by a pronounced faunal change, such that while the fauna of the Berea ("Corry") sandstone has a distinctly Carboniferous facies and is probably to be correlated with the Kinderhook group of the Mississippi Valley, that of the Bedford shale, though its stratigraphic position is above the typical Chemung, has, in connection with the other "Bradfordian" faunas, a distinctly Devonian facies.

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CHANGES IN THE BEHAVIOR OF THE EEL DURING TRANSFORMATION

BY

Bashford Dean

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CHANGES IN THE BEHAVIOR OF THE EEL DURING TRANSFORMATION

BY BASHFORD DEAN

(*Read in abstract before the Academy 13 May, 1912*)

The literature of animal behavior gives as yet little attention to the changes which occur in animals during the period of metamorphosis. This is a gap in our knowledge not remarkable perhaps when we consider how little is yet recorded of the behavior of many types of adult animals, even of common forms. None the less, it is precisely during the period of transformation that one may expect to find clues as to interesting conditions in mind-mechanism, for during this short period adjustments are completed which change, as it were, one functional "species" into another; for an animal may remain for years in its larval form almost unaltered, and it may subside again into a changeless form after a kaleidoscopic transformation. In fact, the more sudden the change in transformation, the more interesting it should be from the point of view of connecting habits with structures, for it would here bring into sharpest relief morphological changes and make them the more easily linked with changes in behavior.

In the larval history of fishes, observations in this field have rarely been recorded. The teleosts, where conspicuous larval stages occur, are little studied, even in the case of those members of the group which have the most complete metamorphosis.

The form-changes of eels have been described by a number of authors (Grassi, Calandruccio, Cunningham, Eigenmann and others), and the changes are so marked that we can readily predict from them striking changes in behavior. That the latter actually occur, and in marked degree, was clearly brought home to the writer when an opportunity came to him in Japan (Misaki) to observe the transformation of a *Leptocephalus* into a *Conger*,—possibly *Conger* (*Leptocephalus*) *malabaricus* (Day).[1] His notes, especially upon its behavior, are perhaps worthy to be recorded on account of the interesting nature of the "larva" and from the fact that this form is not apt to be observed. In point of fact *Leptocephalus* seems rarely to have been kept living in an aquarium

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[1] FRANCIS DAY: "The Fishes of Malabar." Pl. xix. 1865.

more than a few hours. The specimen in question, I may mention, was in perfect condition when taken. It was noticed in the bag of a seine,—by accident rather than by design,—for had the fish not been actively moving at a particular moment, it would have escaped unnoticed on account of its glassy transparency. It proved to be hardy and lived in an aquarium for over three weeks, during this time undergoing its metamorphosis.

September 13. Larva (Fig. 1) almost colorless, even in light of different intensities; it is rarely at rest; it is apt to swim rapidly and with a kind of lurching movement. When advancing slowly, its height, which insures contact with a large surface of water, allows it to move with precision,—in the sense that a pencil held vertically in the first in-bent curve of the fish's body will not be touched by the fish as it advances,—in other words, that the fish does not show lost or slipping movements. When resting, the young fish arranges itself in irregular vertical coils, thus probably keeping its balance. When disturbed (snout touched with a pencil point), the fish retreats tail foremost, the head remaining passive: if disturbed again, the head will be quietly drawn back, the motion starting as before with a withdrawal of the tail and hinder trunk. If disturbed repeatedly, however, the fish will either swim about actively or draw itself into a close coil (Fig. 2). This position, however, it will sometimes assume without artificial stimulus, *e. g.*, after it has become "tired" swimming around the wall of a circular jar. *Leptocephalus* from time to time secretes considerable mucous: this remains attached but is finally "brushed off" (in a mass) at the tail end of the body. Such a bit of slime will occasionally be touched by the young eel when swimming about; it is evidently distasteful, for the young fish speedily frees itself, shaking its head in a curiously energetic way.

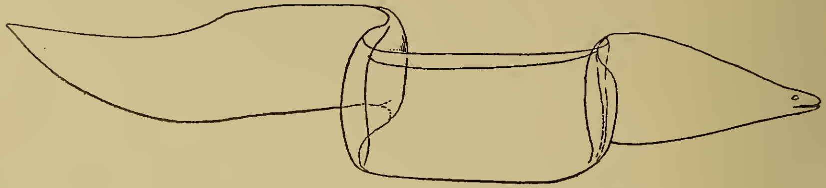

FIG. 1.—*Eel larva.* September 13. About natural size

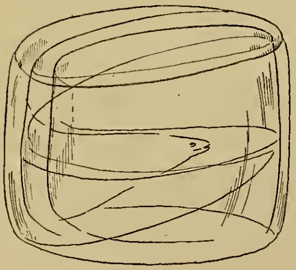

FIG. 2.—*Eel larva.* Retracted position

September 15. The fish is now more easily seen. There is a slight clouding of its transparent sides, especially near the lateral line (Fig. 3). Its eyes are conspicuous and show numerous movements. It is more active than in the earlier stage, sometimes swimming with broad undulations (Fig. 4) different in type from earlier movements. A patch of color, brownish orange, appears on the ventral body wall, just behind the gill opening (jugular villi).

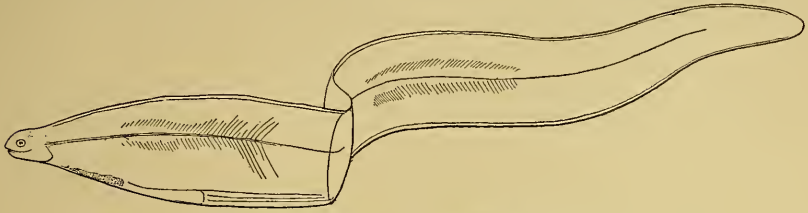

FIG. 3.—*Eel larva.* September 15

September 18. The larval length and breadth are rapidly becoming reduced (Fig. 5). The caudal fin and dorsal ridge appear. The colored jugular patch has now developed into a velvety mass of lighter color, and possibly serves as a larval adhesive organ, which hangs freely in the water. The intestine can be outlined. Pigmentation is noted, especially along the lateral line and on the head-roof, and the entire fish has a faint purplish tone. It remains more often at the surface than before, here occasionally floating and swimming on its side, now and then thrusting its head out of water. It remains longer in one position than heretofore. If disturbed (head touched), it will wriggle its head backward,—and does not initiate the backward movement from the tail as in the earliest stage.

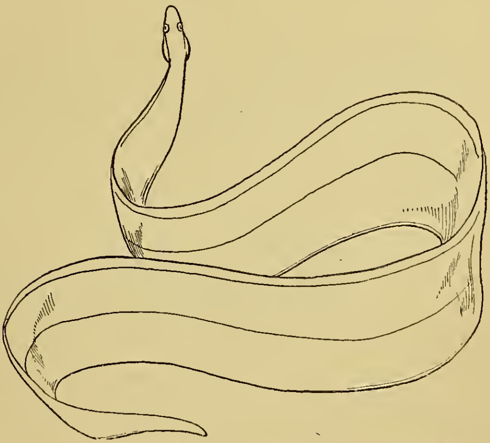

FIG. 4.—*Eel larva.* Position in swimming

September 19. Changes progress rapidly (Fig. 6). The coloration is distinctly purple, with whitish spots near the tail, and pigment patches on the ventral wall of the head and within the neural axis. Vertebræ

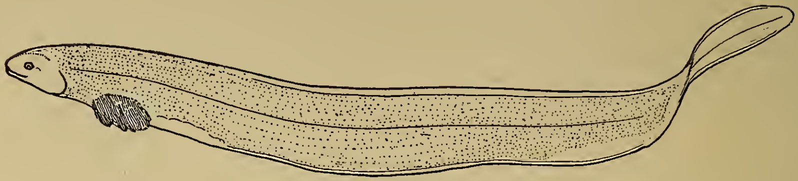

Fig. 5.—*Eel larva.* September 18

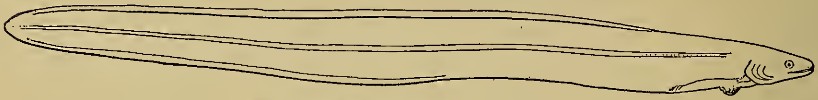

Fig. 6.—*Eel larva.* September 19

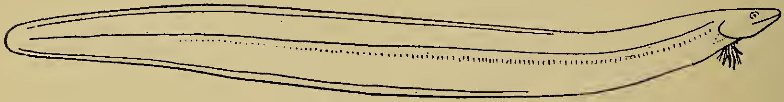

Fig. 7.—*Eel larva.* September 22

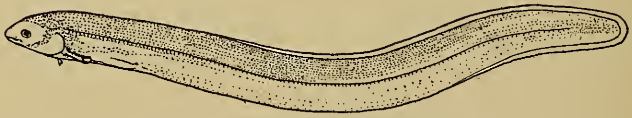

Fig. 8.—*Eel larva.* September 28

Fig. 9.—*Eel larva.* October 2

Figures about natural size

are now seen. The patch of jugular villi is reduced in size. The behavior of the young fish is eel-like. It remains motionless for longer periods, occasionally lifting and turning its head, and there are pronounced movements of its opercula.

September 22. Larval coloration is apparent in the white spots above and below the tail. In general the advances are clearly in the direction of the mature eel. The vertebræ are conspicuous; the visceral wall becomes opaque; the jugular larval organ is represented by a clump of scattered filaments; the gill region is more conspicuous (Fig. 7); the gill arches show the red lamellæ, expand broadly and contract; the mouth opens wide; there is no movement in the neck region; the pectoral fins function; and the swimming is snake-like, with more effort than propulsion, *i. e.*, slipping, unlike the precise movements of earlier stages.

September 26. From now onward, the changes are less noticeable. Larval coloration is retained, *e. g.*, in the light colored spots. The trunk is opaque, even in the gill region.

September 28. At this stage, the last trace of the larval jugular organ was noticed. The body is thickened; the white spots have disappeared (Fig. 8).

October 2. The last stage recorded (Fig. 9). Transformation is practically complete. Measurements of this contrasted with the earliest stage show a surprising shrinkage in the length and height of the young eel,—more exaggerated even, than in the cases described by Grassi. In the present instance, the young fish is about one-half the length of the earliest stage, and one-third of its height, after a growth period of about three weeks. It is another example of the paradox that development may be accompanied by considerable diminution in size.

Especially interesting in the foregoing transformation is the rapidity with which the behavior of the young eel changes. This is not brought out in adequate detail in the present note, but it may be said that the observer could not but feel that the larva behaved like an animal suite of a different species from the one of the days before, or of the days following. This state of affairs predicates, obviously, kaleidoscopic changes in elements of the central nervous system, and astoundingly delicate and rapid adjustments; but whether these can be actually determined, *i. e.*, in the physical characters of the cells of brain and cord, must yet remain an open question. It can be solved only when an abundant material of *Leptocephalus* falls into the hands of a specialist who can bring to his aid the latest neurological technique.

From a phyletic point of view, on the other hand, the origin of the rapidly changing behavior correlated with morphogenetic changes is less difficult to understand. We have, first of all, numerous grounds for concluding that the larval stages of teleosts are secondary, and that eccentric forms,—*i. e,* those with extraordinary fins, colors, outlines,—are derived from "larvæ" in which such extreme structures did not exist. In the case of the eels, therefore, we can reasonably picture a progressive form of development, such, for example, as occurs in many of the older groups of teleosts. We next suggest that within this progressive series of closely similar stages, one stage should become especially important as adapting the young to a particular environment. The young eel then would tend to remain longer unchanged in the special environment favorable to its feeding, movements, lack of pigment, temperature-requirements, etc., and this phase in its life-history would come to supplant the adjacent steps in the progressive series. In other words, if we grant that the development of a young eel (the *montée*) might be accomplished in the space of fifty weeks, and that at the end of this period it completed the fiftieth of its intergrading stages, we could also admit that with the same total period of larval growth certain of the stages might have expanded while others contracted. Thus, to take an example, stage twenty, which earlier may have been passed through in a week, might become successively protracted to two weeks, three weeks, or months. And the stages of the *montée* intervening between twenty and fifty would be correspondingly reduced. The interval was at first thirty weeks, and included thirty stages; it was next, say, fifteen weeks in which to represent thirty stages, and finally in the case of our *Leptocephalus,* it was reduced to the astonishingly short term of three weeks, in which to represent the many stages. In such an instance there can be little question that the marked changes in behavior are correlated with abbreviated phases of development.

PUBLICATIONS

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ANNALS OF THE NEW YORK ACADEMY OF SCIENCES
Vol. XXII, pp. 327–333

Editor, Edmund Otis Hovey

NOTES ON THE HABITS OF A CLIMBING CATFISH *(ARGES MARMORATUS)* FROM THE REPUBLIC OF COLOMBIA

BY

R. D. O. Johnson

NEW YORK
PUBLISHED BY THE ACADEMY
20 December, 1912

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[ANNALS N. Y. ACAD. SCI., Vol. XXII, pp. 327–333. 20 December, 1912]

NOTES ON THE HABITS OF A CLIMBING CATFISH (*ARGES MARMORATUS*) FROM THE REPUBLIC OF COLOMBIA

BY R. D. O. JOHNSON

(*Read in abstract before the Academy 13 May, 1912*)

Introductory remarks, offered by BASHFORD DEAN *at the meeting.*—The group of catfishes (Siluroids) holds a puzzling place among fishes. That it represents one of the ancient groups of bony fishes, there can be no doubt, but whether Siluroids are descended from some special line of ganoids or whether they have been derived through a long series of specializations from some ancestor essentially carp-like remains ever an open question. The trend of later work, certainly, tends to ally them more closely with plectospondylous forms, but many of their most important structural characters have never been explained on such a basis.

Thus, the limb-girdles of some of the catfishes, with their accompanying muscles, have appeared to be primitive, and there has, as far as I am aware, been adduced no evidence to show that these structures were derived from highly specialized conditions of such living plectospondyls, for example, as characinids. The habits of Siluroids, which would help to explain the significance of these abdominal structures, have not been known to be remarkable, and there is no suggestion, therefore, that the characters in question might but be interpreted as highly modified rather than primitive. Accordingly, the present paper of Mr. R. D. O. Johnson merits, I believe, the attention of the Academy, for he shows that under conditions of stress, the ventral structures of the catfish *Arges* have an especial value to the fish in enabling it to creep against the strongest currents and to climb with great rapidity and skill. The conclusion, therefore, is evident that we may now reasonably interpret the puzzling fin-structure of Siluroids as developed in relatively recent times, and as having little significance in terms of more ancient groups.

Mr. Johnson, it may be mentioned, spent several years in the highlands of the Republic of Colombia, and although the region he studied has been visited by but few naturalists, it is nevertheless hardly to the credit of our "cloth" that these observations on fishes should first be made by a mining engineer.

The creeks and rivers of the Andes Mountains in the Republic of Colombia, South America, are torrential in character. The great majority of them are but a succession of falls, cascades, pot-holes and short "riffles." The rainfall in the mountains is heavy and the rock underlying the stream beds is schistose in character and comparatively soft. The rate of erosion is exceedingly rapid, yet the grade lines of these streams stand at high angles. This unstable condition seems to be due to the elevation of the Andes during a late geological period. The heavy rainfall, at times amounting to four or five inches within a few hours, produces floods of immense volume. These go charging down the canyons with fearful fury, and at times it would appear that nothing could withstand their sweeping energy. Yet these turbulent waters are the habitat of fishes so wonderfully adapted to their surroundings that they are able to grow and to multiply in great numbers.

In external appearance they resemble the catfish or horned pout of the north. The skin is smooth and scaleless. The color is a dark mottled gray shading into a slightly yellowish tint on the posterior parts. They rarely attain a length greater than twelve inches. As an article of food they are esteemed by the natives and are well known by the local name "Capitan." They have lately been described by C. Tate Regan as *Arges marmoratus*.[1]

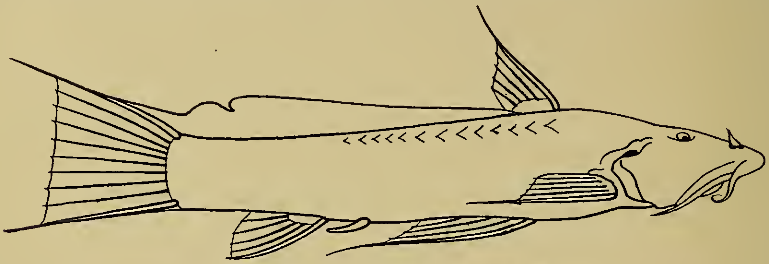

FIG. 1.—*Arges marmoratus* Regan; side view

Under usual conditions they are clumsy and awkward swimmers, wriggling through the water like tadpoles, but as creepers and climbers they are without rival in the fish family. The mouth is small, but is surrounded by a broad, soft, rubber-like flap, very thin and flexible at the edges (Fig. 2). It is a sucker mouth and the entire mechanism is so perfectly adapted to the needs of the fish that it finds no difficulty in firmly attaching itself to any convenient object. It is this ability to make a quick anchorage that enables the fish to stay at home when nature seems bent upon sweeping the canyons and water-courses clear of everything movable.

If, however, these fish were able only to keep themselves from being washed out in flood times, they would be insufficiently equipped to maintain an existence in these mountain streams. If they depended upon their imperfect swimming alone as a means of locomotion, whatever migratory movement they attempted would inevitably have to be made

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[1] Trans. Zoölogical Society of London, XVII, p. 314. 1904.

in a down-stream direction. The final result would be the same as though they were unprovided with a means of anchoring themselves at will. But they are equipped with another and very efficient apparatus for locomotion. The flat sucker mouth is half of the mechanism; the other half is located on the belly. Under the skin of the ventral side, just behind a line joining the pectoral fins, there is a triangular bony plate to which are attached the ventral fins (Fig. 2). The main anterior ribs of these fins are broad and flattened, and the flat surfaces are thickly studded with small, sharp teeth pointing backwards. The triangular plate and its attached fins are free to move in a longitudinal direction through a distance equal to about one-sixth of the length of the fish. This movement is accomplished by means of four muscles in two pairs attached to the plate; the anterior pair extending from their attachments on each side of the plate forward to the middle point on the bony arch just below the gill openings; the posterior pair extending from an

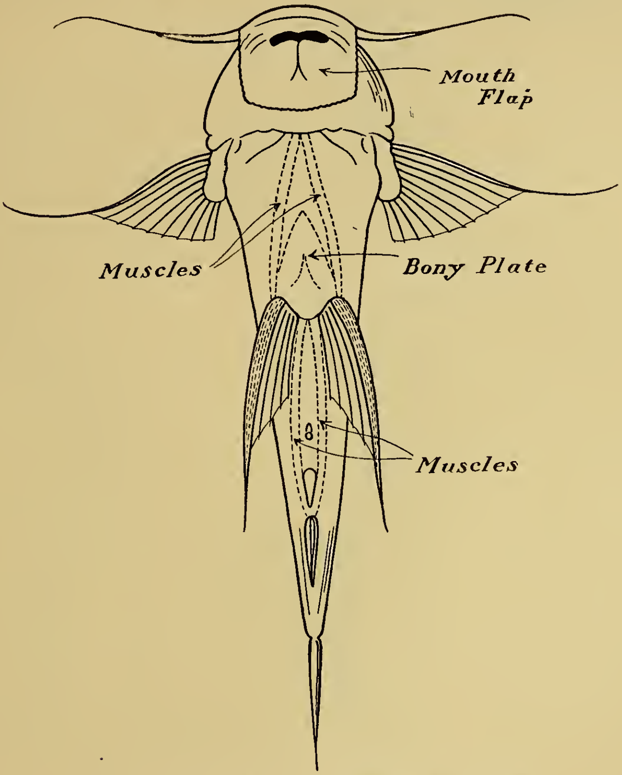

FIG. 2.—*Arges marmoratus* Regan; ventral view

attachment at the center of the posterior edge of the plate to the anal fin. It is evident that the fish is able to create a suction pressure in the region of the plate, though how this is accomplished is not apparent from the structure.

By means of the alternate action of the mouth and of this curious apparatus, the fish is able to creep against a current that would baffle its efforts entirely, if it relied alone upon its fins and tail. When it is engaged in creeping or in sticking fast to some object, the sucker mouth necessarily is closed. It is evident that the gills must be supplied with the life-maintaining flow of water through some other avenue. At the upper extremity of each gill slit there is an orifice provided with a valve opening inward (Figs. 1 and 3). During the diastole of the gill covers, the water flows inward through the orifices and is expelled through the gill slits during the systole.

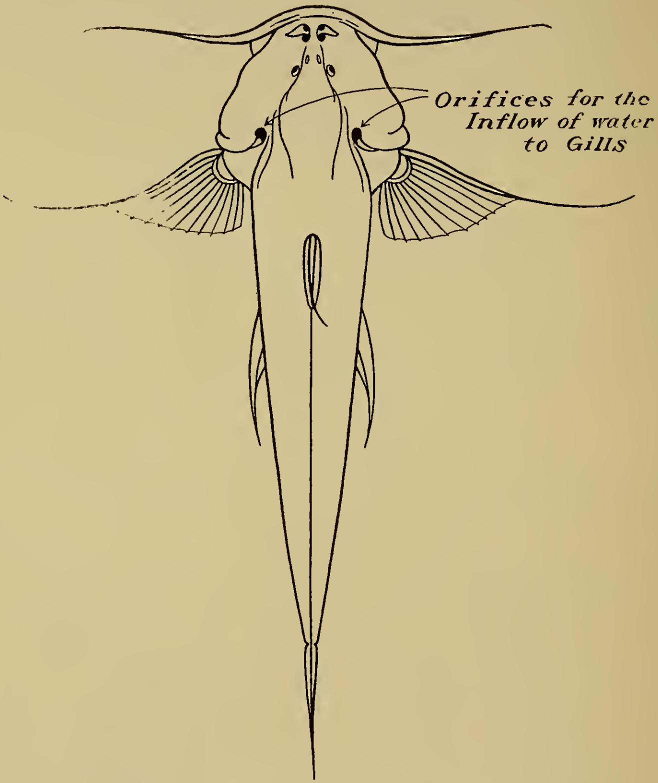

FIG. 3.—*Arges marmoratus* Regan; dorsal view

On clear sunshiny days, these fish may be seen in the depths of the clear water hitching themselves along over the surfaces of rocks, occasionally swimming short distances in the more quiescent places, but seeming to depend for locomotion primarily upon their creeping mechanism. They are to be found in all parts of these mountain streams, from the most slender tributaries to the foot of the mountains. It is evident from this fact that they are able to travel up stream. They are too

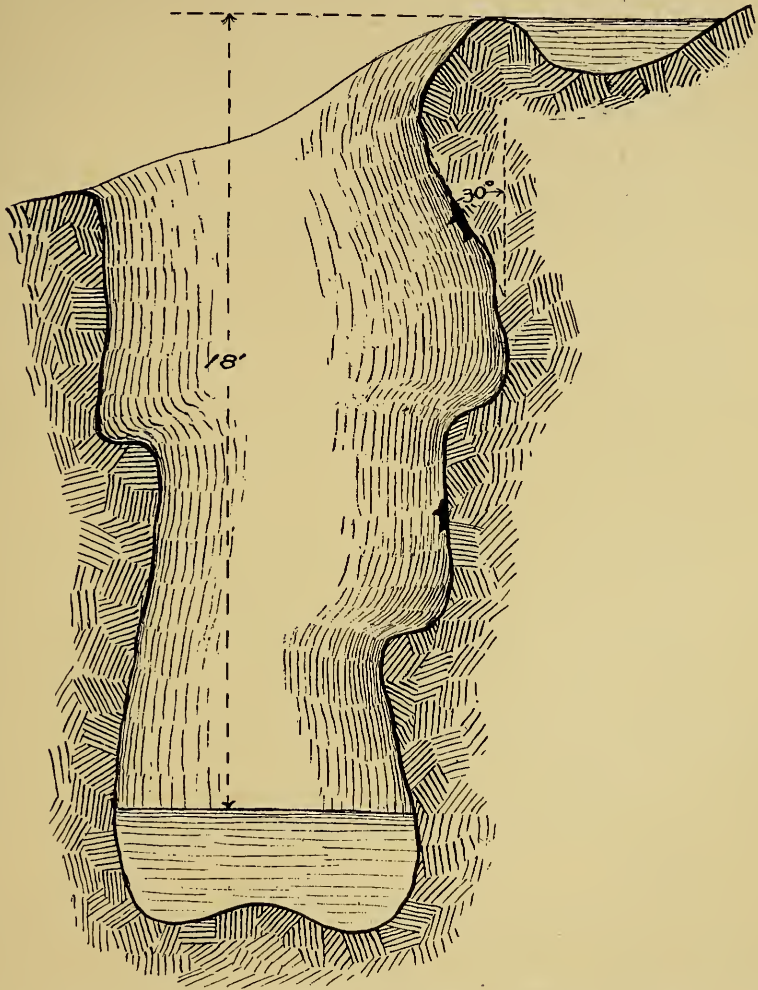

Fig. 4.—Section of a pot-hole, twenty-two feet deep, in Santa Rita Creek, Colombia, showing "capitanes" ascending its rocky walls

sluggish in movement and are provided with a swimming apparatus altogether too inefficient to enable them to dash up the high and frothy falls.

At one time, the writer had occasion to divert the water of a small mountain stream so that access could be gained to a deep pot-hole from which the water, rock and gravel were subsequently removed. This pot-hole was twenty-two feet deep, nearly circular in horizontal cross-section and it varied in diameter from six to ten feet. Generally, the sides approached the vertical and in some parts inclined inwards. When the water had been lowered to within four feet of the bottom, the remaining water was seen to contain a large number of "capitanes." They were greatly excited and distressed and were swimming and creeping about in all directions. A small stream of water in a thin film ran down one side of the pot-hole from a leak in the dam above. Several fish, after nosing around the edge of the water, discovered this small inflowing stream and started to creep up in it, but becoming frightened by the movements of the working men near, dropped back. When work was stopped for the noon hour, four of the smaller fish started up, following the thin stream of water. The water ran over their noses, down their backs and trickled off their tails in small streams. They would hitch themselves up rapidly for the distance of a foot or so and remain quiet for a minute or two; then another foot and another rest. In half an hour, the four had reached the water in the pool at the foot of the dam above. In making the ascent, they were obliged to pass a part of the wall, about two feet in length, that inclined inward at an angle of about 30° from the vertical. When they reached this overhanging part, in no observable manner did they change their tactics, but they ascended it as rapidly and safely, and apparently with no more effort than the other portion of the wall. During the afternoon, several more of the fish climbed out. A large number were in the water at the bottom of the hole when work was suspended for the evening. In the morning not a fish remained.

For the greater part, the path followed by the fish in making their ascent lay over smooth, water-worn surfaces free from any coating of vegetable matter. The upper part, however, was covered by a thin film of an alga-like growth that may have served for the engagement of the sharp-pointed teeth on the movable ventral fins. The total vertical distance through which the fish climbed measured eighteen feet. When undisturbed, they covered the distance without a slip or fall. The water, diverted around this pot-hole, flowed through a large pipe and fell from the end upon the steeply inclined water-worn rock at the side of the channel below. A day or two after the water had thus been diverted, a dozen or more of these fish were observed to be clinging to the rock at the foot of the fall at the end of the pipe. They were evidently on their way up stream, but had encountered an artificial condition that interrupted their further progress. They were nosing about in search of a small stream or film of water sufficient to keep their gills wet and to lead them to the main body of water above. As there was no such stream, their further progress was prevented. They made no observed attempt to swim up the fall, but confined their efforts to making short excursions up the rock above the water. Failing to find any leading stream, they crept back.

They deposit their eggs in the deepest pot-holes and attach them individually to the under sides of large rocks.

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ANNALS OF THE NEW YORK ACADEMY OF SCIENCES
Vol. XXII, pp. 335-337, Pll. XXXV-XXXIX

Editor, Edmund Otis Hovey

THE KINGSTON, N. M., SIDERITE

BY

Edmund Otis Hovey

NEW YORK
PUBLISHED BY THE ACADEMY
27 December, 1912

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[ANNALS N. Y. ACAD. SCI., Vol. XXII, pp. 335–337, Pll. XXXV–XXXIX.
27 December, 1912]

THE KINGSTON, N. M., SIDERITE[1]

BY EDMUND OTIS HOVEY

(*Read before the Academy 4 November, 1912*)

In the year 1891, a prospector was ransacking the region along the North Branch of Percha Creek, near the Solitary Mine, about four miles north of Kingston, Sierra Co., New Mexico, in a search for horn silver (cerargyrite), when he stumbled upon what he supposed to be a solid mass of the ore for which he was hunting. This was lying upon a ledge of granite and, according to the account of the finder, had been brought to view by erosion. The approximate position of the locality is latitude 32° 58′ North, longitude 107° 50′ West. A small fragment was broken off and sent to an assayer, who informed the finder as to the real nature of his specimen. Another small piece was sawed from the other end of the mass. These two pieces would weigh together about 5 ozs. (142 gm.), while the mass as delivered to the Foote Mineral Co. weighed 28 lbs., 6 ozs. (12,870 gm.); hence the total original weight was about 28 lbs., 11 ozs., or 13,012 gm. Mr. Warren M. Foote of Philadelphia very kindly sent the specimen to me for description and gave me the foregoing information regarding its discovery and history.

The iron, which is a holosiderite, has been named Kingston from the post office nearest to the place of discovery. As found, it was lenticular in shape, and its dimensions were 204 x 167 x 70 mm. No sign of the original crust remains, and the "thumb marks" have been much obscured by oxidation. The exterior, however, presents several broad, shallow depressions, which are clearly shown in Plates XXXV and XXXVI, but nothing to indicate which was the brüstseite. Crevices along which oxidation has taken place to a considerable degree penetrate the mass along the plates and are particularly noticeable in Plate XXXV, fig. 1 and Plate XXXVI, fig. 3. A combination of these cleavage crevices permitted the breaking out of the fragment that was first submitted to assay. The surface is thickly indented with oxidation pits 1-3 mm. across and shallow in proportion to their diameter.

The material furnished me for investigation consisted first of the whole mass and then of the two end pieces and seven slices into which

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[1] Published by permission of the Director, American Museum of Natural History.

the mass was first cut by the Foote Co., two fragments for specific gravity determination and three for chemical study. The last, aggregating about 50 gm. in weight, were sent to Booth, Garrett & Blair of Philadelphia for analysis, with the following result:

	Per cent
Fe (by difference)	92.376
Ni	6.980
Co	0.505
Cu	0.018
S	0.014
P	0.099
Si	0.008

The analysts report the apparent presence of a trace of some other element, probably of the iron-platinum group of metals, but state that they were unable to isolate and determine it in the amount of material available and that it must be present in variable quantities.

The specific gravity as determined at the American Museum on a fragment weighing about 12 gm. is 7.63. This is a low value, even when the small percentage of Ni + Co present is taken into consideration.

End piece No. 1 contains the angular hole left by breaking out the fragment for assay. As submitted to me, this piece was about 40 mm. thick and weighed 1174 gm. The Widmanstätten lines (Pl. XXXVII) were traceable over the whole polished and etched surface, but they were obscured by a flecky granulation extending likewise over the whole surface. The flecks, whose appearance reminds one of the particles making up a flocculent chemical precipitate, are irregular in outline and are from 0.4 to 0.5 mm. across, seldom reaching the latter dimensions. They have no particular orientation and are so strongly developed in places as to suggest an approach to ataxitic structure. This portion of the mass closely resembles Tazewell in appearance. The etched surface of slice No. 1 was about 13 mm. distant from that of the end piece. It showed the flocculent granulation over about three fourths of its surface (Pl. XXXVIII), the remainder being occupied by a subcentral oval area about 90 x 40 mm. in size in which the kamacite was practically free from granulation. In the succeeding slices, the oval clear area expanded until in slice No. 6 there was no granulated area (Pl. XXXIX). End piece No. 2, however, showed a bright fleck here and there. The granulated portion of the mass, therefore, originally formed a cap over a roughly cone-shaped development of iron that was practically free from the flecks.

Turning now to the other features of the meteorite we may say that the Widmanstätten lines are well developed, forming kamacite bands from 0.5 to 1.5 mm. broad, but the usual width is 0.75 mm., where they are not doubled or trebled. Some were measured that were practically continuous for a length of from 75 to 85 mm. Neumann lines are abundant and distinct, though occasionally obscured by a minute network of curved lines. Tænite is practically absent and plessite is extremely subordinate in development. Thin, short lines of schreibersite may be seen here and there, some of which are associated with little nodules of troilite and some with the bands of kamacite. About fifty small nodules of troilite were noted, varying in size from 1 to 8 mm. in diameter. Lawrencite exuded rather freely from the crevices in the slices during the dampness of summer.

The iron is octahedral in structure, and the breadth of the lamellæ throw it into the medium octahedrites (OM) of Brezina's classification.

A circle whose radius is 70 miles would pass through or close to the places of origin of the following New Mexico siderites: Kingston, Luis Lopez (Magdalena), Oscuro Mts., El Capitan and Sacramento Mts. The irons, however, seem to be independent falls.

PLATE XXXV

Kingston meteorite. Front and back view of the original mass. ½ natural size

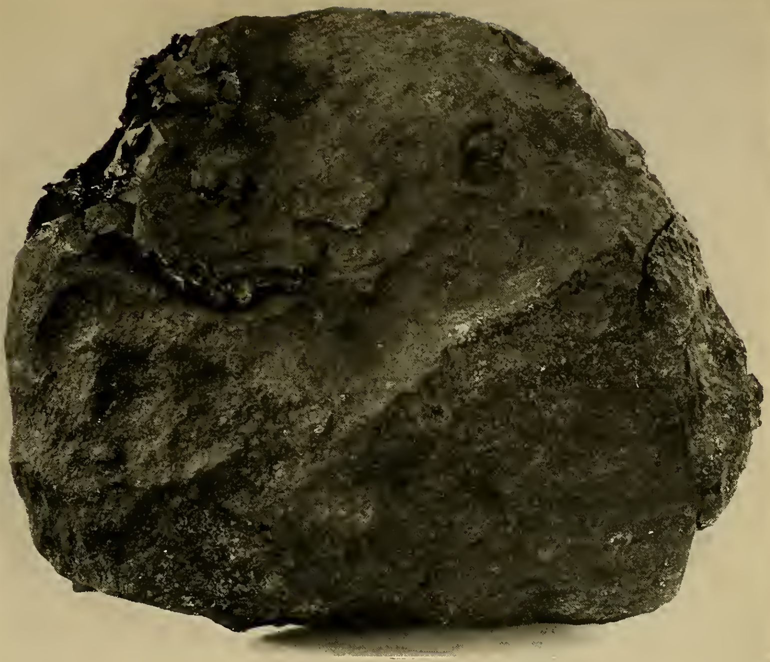

Plate XXXVI

Kingston meteorite. Three edge views. ½ natural size

PLATE XXXVII

Kingston meteorite. Polished and etched surface of end piece No. 1, showing the fine granular structure obscuring the Widmanstätten lines over the entire surface. Natural size.

PLATE XXXVIII

Kingston meteorite. Slice No. 1. Polished and etched surface showing a combination of the flocculent granulation with an area from which the granulation is absent. Natural size.

PLATE XXXIX

Kingston meteorite. Slice No. 6. Polished and etched surface from which the flocculent granulation is practically absent. Natural size.

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ANNALS OF THE NEW YORK ACADEMY OF SCIENCES
Vol. XXII, pp. 339–423

Editor, Edmund Otis Hovey

RECORDS OF MEETINGS CHARTER, CONSTITUTION AND MEMBERSHIP IN 1912

OF THE

NEW YORK ACADEMY OF SCIENCES

WITH INDEX TO VOLUME XXII

NEW YORK
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[ANNALS NEW YORK ACADEMY OF SCIENCES, Vol. XXII, pp. 339–414.
20 April, 1913.]

RECORDS OF MEETINGS

OF THE

NEW YORK ACADEMY OF SCIENCES.

January to December, 1912.

BY EDMUND OTIS HOVEY, *Recording Secretary.*

LECTURE.

3 JANUARY, 1912.

Edward E. Barnard: THE PLANET MARS.

BUSINESS MEETING.

8 JANUARY, 1912.

The Academy met at 8:23 P. M. at the American Museum of Natural History, Vice-President Woodman presiding.

The minutes of the last business meeting were read and approved.

The following candidates for membership in the Academy, recommended by Council, were duly elected:

ACTIVE MEMBERSHIP.

A. B. Pacini, Board of Water Supply, New York.
Henry Arctowski, New York Public Library.

ASSOCIATE MEMBERSHIP.

Charles R. Fettke, Livingston Hall, Columbia University.

The Recording Secretary announced that a special fund had been provided so that during 1912 each of the four sections of the Academy might have $100 at the disposal of the sectional officers for expenses or honoraria connected with an effort to make the meetings more interesting to the general public and extend the influence of the Academy. A vote of thanks was extended to the unnamed donor.

The Academy then adjourned.

EDMUND OTIS HOVEY,
Recording Secretary.

SECTION OF GEOLOGY AND MINERALOGY.

8 JANUARY, 1912.

Section met at 8:28 P. M., Vice-President J. E. Woodman presiding. Thirty-three members and visitors were present.

The minutes of the last meeting of the Section were read and approved.

In the absence of Dr. Charles P. Berkey, Secretary of the Section, Dr. E. O. Hovey was elected Secretary *pro tem.*

The Secretary *pro tem* presented an application in the name of Mr. George Borup for a grant of $500 from the Esther Herrman Research Fund, as a contribution to the Crocker Land Expedition which he and Mr. Donald B. MacMillan were organizing under the auspices of the American Museum of Natural History and the American Geographical Society. On motion, the application was referred to the Committee on Grants from Research Funds with power.

The programme for the evening was then taken up as follows:

A. B. Pacini, THE METAMORPHISM OF PORTLAND CEMENT. I.

Remarks were made by Professors Kemp, Woodman and Grabau.

The paper has been published as pages 161–224 of this volume.

Dr. **E. O. Hovey** gave a brief summary account of the Washington meeting of the Geological Society of America and a few of the papers presented there.

Professor **A. W. Grabau** gave a similar account of the Washington meeting of the Paleontological Society.

The Section then adjourned.

EDMUND OTIS HOVEY,
Secretary pro tem.

SECTION OF BIOLOGY.

15 JANUARY, 1912.

Section met at 8:15 P. M., Vice-President Frederic A. Lucas presiding.

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

Henry Fairfield Osborn, PHYLOGENY AND ONTOGENY OF THE HORNS OF MAMMALS.

Henry Fairfield Osborn, SKULL MEASUREMENTS IN MAN AND THE HOOFED MAMMALS.

Frederic A. Lucas, WHALING IN THE OLDEN TIME.

SUMMARY OF PAPERS.

Professor **Osborn** said in abstract: The recent discovery of the modes of origin of the horns in the titanotheres, a perissodactyl group remotely related to horses, tapirs and rhinoceroses, permits of a comparison of phylogenesis with the ontogenesis of the horns in bovine mammals. The latter is based upon an osteological series recently prepared by Mr. S. H. Chubb, the former is based on the rich phylogenic series of Eocene titanotheres in the American Museum of Natural History. The conclusion is that ontogeny closely recapitulates phylogeny, that the genesis is gradual or continuous, that the horns arise definitely and determinately. In the bovine series it seems, in accord with the conclusions of Dürst, that the horn first appears as a circular thickening of the skin, accompanied by accelerated growth of the hair preparatory to the formation of the keratin of the horny substance, at a period considerably prior to any sign of the horn in the bony structure of the frontals. This raises the problem, which will form the subject of a special paper in the Annals of the Academy, as to what element first arises in connection with horn evolution, namely: (1) the psychic, or desire to use the horn; (2) the epidermal callous or keratin protection of the bony horn center, or (3) the bony or osseous horn itself. It would appear that the psychic tendency must precede the epidermal and that the latter precedes the osseous, but this disputed point requires further investigation.

The paper was illustrated with lantern slides, drawings and specimens.

Professor **Osborn,** in his second paper, said in abstract: Comparative anatomists and zoölogists have been slow to introduce into mammalogy systems of measurement by indices and ratios, which have proved of such universal value in anthropology. It is found among the hoofed mammals, from studies undertaken by the author with the co-operation of Dr. W. K. Gregory, that cephalic indices and limb ratios between different segments of the skeleton are far more significant than systems of direct measurement. These cephalic indices of the gradual changes of proportion between different regions of the skull have the value of specific characters and sharply distinguish members of different phyla. For example, in the cross between the horse (*E. caballus*) and the ass (*E. asinus*), it is found that the cephalic indices are transmitted as pure non-blending characters.

Among the most significant indices are the following: (1) the cephalic, which is obtained by dividing the total or basilar length of the skull by the zygomatic breadth; (2) the cranial, which is obtained by dividing the basilar length by the postorbital length of the skull; (3) the facial, obtained by dividing the basilar length by the preorbital length of the skull, etc. The horses show proopic dolichocephaly, or elongation of the face, and a static condition of the cranium, while the titanotheres, in contrast, show opisthopic dolichocephaly, or elongation of the cranium, and abbreviation of the face. Like the phyletic differences of proportion between the horse and the ass, these differences are most exactly expressed by the method of indices.

The application of the ratio method to the limbs of the hoofed mammals has again produced most surprising results. It is found that mammals of different phyla adapted either to "weight" or to "speed" converge respectively toward typical "weight" or "speed" ratios, which are obtained by dividing the length of the lower segments, tibia and radius, respectively, by the upper segments, femur and humerus, metacarpus and metatarsus, respectively. These "weight ratios" and "speed ratios" are far more significant as regards function and phyletic change than the actual or direct measurements.

Dr. **Lucas** exhibited lantern slides illustrating some interesting pictures from old works on whaling and showing the methods practiced by the early Japanese, European and American whalers.

The Section then adjourned.

WILLIAM K. GREGORY,
Secretary.

SECTION OF ASTRONOMY, PHYSICS AND CHEMISTRY.

22 JANUARY, 1912.

Section met at 8:15 P. M., Vice-President Campbell presiding.

The minutes of the last meeting were read and approved.

Dr. **F. M. Pedersen** of the College of the City of New York was then elected Secretary of the Section for the year 1912.

The following programme was offered:

C. C. Trowbridge, RECENT DISCOVERIES CONCERNING A CHEMICALLY ACTIVE MODIFICATION OF NITROGEN.

William Campbell, SOME NOTES ON IRON AND STEEL.

The Section then adjourned.

F. M. PEDERSEN, *Secretary.*

SECTION OF ANTHROPOLOGY AND PSYCHOLOGY.

29 January, 1912.

Section met in conjunction with the American Ethnological Society at 8:15 p. m., Gen. James Grant Wilson presiding.

The minutes of the last meeting were read and approved.

The following programme was then offered:

Pliny E. Goddard, Notes on the Jicarilla Apache.

Summary of Paper.

Dr. **Goddard** in his paper said: The Jicarilla Apache are, from the point of view of material culture, a buffalo-hunting Plains people dwelling in skin-covered tipis. Their social organization differs from that of the Navaho and neighboring Pueblo tribes in lacking exogamous clans, there being two geographical divisions with ceremonial and political, but not marriage-regulating, functions. Among the ceremonies the speaker mentioned an annual feast celebrated on the 15th of September and probably connected with the corresponding celebration at Taos, the conspicuous feature of both consisting in a relay race. A ceremony resembling the Bear Dance of the Southern Ute is performed in cases of illness and is characterized, among other things, by sleight-of-hand performances of masked dancers. The girls' puberty celebration is very prominent; a distinctive feature of the Jicarilla form of this ceremony seems to be the association of a young man with the adolescent girl. Among the myths of the Jicarilla that of the twin heroes is prominent.

In the course of the discussion Dr. Goddard stated that he had been unable to discover myths definitely connecting the mythology of the Jicarilla with that of their linguistic congeners in California and the Far North. In reply to another query he expressed his belief that, owing to the linguistic differentiation of the Apache, this tribe must have occupied its southwestern habitat a considerable period before the first historical notice of it.

The Section then adjourned. F. Lyman Wells, *Secretary.*

BUSINESS MEETING.

5 February, 1912.

The Academy met at 8:21 p. m. at the American Museum of Natural History, Vice-President Woodman presiding.

The minutes of the last business meeting were read and approved.

The following candidates for active membership in the Academy, recommended by Council, were duly elected:

Charles E. Sleight, Ramsay, New Jersey.
R. B. Earle, New York University.

On motion, the following minute was unanimously adopted and ordered to be engrossed and transmitted to the family of the late Mr. Charles F. Cox:

The Academy suffers irreparable loss through the death, on 24 January, 1912, of Mr. Charles Finney Cox. For thirty-six years an Active Member and Fellow of the organization, his influence has been felt from the first in all progressive movements of the Academy. He served the Academy diligently as Curator, 1884, 1885; Councilor, 1891, 1892; Treasurer, 1893–1907; President, 1908, 1909. At the time of his death he was again acting as Treasurer. When President he was active in the organization of the Academy's Darwin Centennial celebration, and he delivered a masterly address on Darwin at the close of each of his two years of incumbency.

Always the friend of investigation, he was one of the founders of the Scientific Alliance of New York, the first association of the scattered organizations that were striving independently to advance the interests of science in the city. Some five years ago he was again active in establishing the closer affiliation which now obtains among them.

Mr. Cox's consuming interest outside of his daily duties in the railways of the New York Central system was the study of the life and writings of Charles Darwin. In its pursuit, he became a keen and devoted collector of Darwiniana, and the portraits, first editions, manuscripts and other priceless memorials which he brought together constitute a remarkably complete exhibit of Darwin's scientific work and influence upon the thought of the last fifty years. Another of his avocations was microscopy, in which he was active for many years, while his interest in botany was evidenced by his participation in the founding of the New York Botanical Garden and in its management up to the time of his decease.

In character, Mr. Cox was a man of great simplicity and natural refinement. He attracted and held his friends with bonds of attachment that were altogether exceptional in their strength. While he will be missed and mourned by all who knew him, the sense of loss is peculiarly deep in the circle of the New York Academy of Sciences.

To his family the Academy extends its profound sympathy.

The Academy then adjourned.

EDMUND OTIS HOVEY,
Recording Secretary.

SECTION OF GEOLOGY AND MINERALOGY.

5 FEBRUARY, 1912.

Section met at 8:31 P. M., Vice-President Woodman presiding.

In the absence of the Secretary, Dr. Hovey was elected Secretary *pro tem.*

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

E. O. Hovey,	The Amalia Farm Meteorite.
Vernon F. Marsters,	A Sketch of the Physiography and Early Mining Developments of Peru.
Henry S. Washington,	Relations of the Feldspars, Lenads and Veolites.
George H. Girty,	On Some Fossils of the Lykins Formation. (Read by Title.)

Summary of Papers.

Dr. **Hovey** exhibited a polished and etched slice of the iron meteorite from the Amalia Farm near Gibeon, Africa, and called attention to the interesting curvature of the Widmanstätten lines in certain portions of the slice, apparently due to the softening of the neighboring surface of the mass as it passed through the air; also a line of discordance between the lamellæ apparently due to welding by impact of two masses or two fragments of the same mass before the meteorite reached the earth.

Mr. **Marsters** in his paper described the coastal plains and cordilleras of Peru and gave sections at several points from the sea to the summit of the eastern range of the Cordilleras, the petroleum deposits along the coast and the great deposits of coal, Lake Titicaca and the mines of gold, silver, copper and vanadium along the contacts of the eruptive rocks with the sandstones and the shales of the middle and eastern Cordilleras.

Dr. **Washington** in his paper gave an ingenious regrouping of the molecules in the standard analyses of the feldspars and related minerals, bringing out the isomorphism of the groups more clearly than is done by other methods of writing the formulas, provided one can admit that silicon acts as a base as well as an acid.

The Section then adjourned.

Edmund Otis Hovey,
Secretary pro tem.

SECTION OF BIOLOGY.

12 February, 1912.

Section met at 8:15 p. m., Professor Bashford Dean presiding.

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

John D. Haseman, Some Factors of Geographical Distribution in South America.

This paper has been published as pages 9–112 of this volume.

The paper, which was illustrated with maps and diagrams, was discussed by Professor Dean, Dr. W. D. Matthew and others.

The Section then adjourned.

William K. Gregory,
Secretary.

SECTION OF ANTHROPOLOGY AND PSYCHOLOGY.

26 February, 1912.

Section met at 8:15 p. m. in conjunction with the New York Branch of the American Psychological Association, R. S. Woodworth serving as chairman.

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

J. E. Hickman, The Influence of Narcotics on Physical and Mental Traits of Offspring.

A. E. Chrislip, Auditory and Visual Memory.

Henry H. Goddard, The Heredity of Mental Traits.

Summary of Papers.

Dr. **Hickman** said in abstract: The purpose of the study was to learn if the use of narcostimulants (tea, coffee, tobacco and alcohol) had any effect on the offspring. The research extended over a period of four years. It included 306 families with 2,560 children; 620 of this number were students of Murdoch Academy, Utah. These were carefully measured by medical experts and teachers to get their physical and mental status. The measurements and examinations included height, weight, eyes, ears, nose, throat, teeth, heart, lungs, stomach, spleen, liver, kidneys and nervous condition. A record of the death-rate in the families was obtained as well as a record of the student's intellectual standing. The students were divided into eight claasses, according to the kinds and quality of stimulants used by the parents.

The examination showed: first, that there was on an average a very decided difference between the offspring of abstainers and those of users, even where tea or coffee was used by only one parent, for the offspring of the abstainers were superior in size, intellect and bodily condition to those of the caffein parents; secondly, as the use of caffein was increased by the parents, from once to three and four times a day, a gradual decrease in height, weight, bodily condition, etc., of the offspring was manifest; thirdly, in families where not only tea and coffee were used, but also tobacco, the children were still more inferior mentally and physically, increasingly so with the increase of caffein drinks in connection with tobacco; fourthly, where alcohol was used with the above narcostimulants the lowering of the physical and mental status was very marked.

Comparing all the offspring of the narcostimulant parents with those from abstaining parents, the latter were found to be better in all the 22 measurements than the former. Some of the differences were very great, especially in weight, height, eyes, ears, physical health and rate of mortality. There are over 100 per cent more eye, ear and physical defects in the offspring of narco-parents; 72 per cent more children died in this than in the abstaining class; 79 per cent of the narcostimulant families had lost one or more children, while only 49 per cent of the abstaining class had lost any children. It was also shown that the death-rate of the parents in this latter class was 41 per cent higher than in the former. The research also brought out the fact that it took the offspring of the narcostimulant parent eight tenths of a year longer to graduate from the grades. In the Academy they were on an average a year and seven months older than the students from the abstaining class.

Mr. **Chrislip** said in abstract: Experiments have been carried on in the psychological laboratory of Columbia University and elsewhere for the purpose of comparing visual and auditory memory. The points investigated in the first experiment were to determine: the number of repetitions required by each sense to reproduce in a certain order certain total series of like construction; the average number of characters of a series recalled in their proper order for each repetition of series of like construction for each sense; and to determine, if possible, the best material for testing the two senses.

The material used consisted of numerals, nonsense syllables and words. Series composed of 12 and 16 characters of each material were used in testing both senses.

The result shows that when series of 12 numerals similarly constructed were presented to the two senses, that out of 26 cases 20 are visual, 8 auditory and 8 show no difference. In the case of the series of 16 numerals, 19 visual, 4 auditory and 13 show no difference. With 12 nonsense syllables there are 15 visual and 15 auditory, the rest showing no difference, but for 16 nonsense syllables, 25 visual, 7 auditory and 4 show no difference. With the 12 words there are 14 visual, 10 auditory and 12 no difference; with 16 numerals, 22 visual, 9 auditory and 5 show no difference.

For each repetition of each series the result shows that in the memory tests for visual reproduction the greater average number is reproduced. The nonsense syllables were the best material, as they offered few combinations or devices for memorizing them.

Experiments, in which stories of 100 words each have been used to test the two senses, have been carried on for some time. The two senses have been tested for both immediate and delayed recall. In both the immediate and the delayed reproductions the visual has been better than the auditory. There is an experiment now in operation in which the method is somewhat different from that in the former experiments conducted with logical material. While the results are not all determined the indications are that the auditory may surpass the visual.

Dr. **Goddard** said in abstract: It is not the purpose at the present time to present any results, but rather to make some suggestions and point out possible lines of research in the hereditary transmission of mental traits which may be of interest to psychologists.

In connection with our studies of the cause of mental deficiency at the training school at Vineland, much material has been accumulated showing the hereditary transmission of deficiency. In connection with these data many facts have come to hand which make it clear that not only deficiency, but many positive traits are directly transmitted. It is further suggested that psychology would gain valuable data and contributions to many of its problems from a study of this question of heredity. Indeed, it seems quite possible that many problems which are now so complex as to elude our powers of analogy would be easily analyzed if we were able to study the heredity problem and thus eliminate the hereditary factor. For example, if the goodness of memory depends, as Professor James said, upon the natural retentiveness of the brain tissue plus the logical association that the individual establishes, then we may reasonably expect that the condition of the brain tissue may be a quality that is transmitted and could be eliminated through the study of mode of transmission; or, in other words, we could determine to what extent the differences in memory are due to acquired factors.

It would seem equally possible that sensory conditions may be traced through families, just as peculiar eyes or eyesight, peculiar hearing, kinesthetic sensations, taste, or smell may be dependent upon organic conditions which may be found to be directly transmitted. The inborn habits or instincts are so bound up with acquired habits that it makes a very complex problem. It seems quite possible that a study of the instinctive activities of members of different generations might reveal to us a good deal about the nature of instinct and its transmission which would have very important bearings upon many of our problems of instinct and emotions. Even the study of such a complex problem as the inheritance of mental deficiency may possibly yield us some most important results.

It seems hardly likely that mental deficiency is due to the absence of any *one* characteristic, but of several, and that it may be pictured more as though normal mentality is the result of a hundred factors of which a person must have, say, seventy-five in order to have what is called normal mentality. Now the twenty-five that are lacking may be any twenty-five, perhaps, in the whole list and a tracing of the hereditary traits might lead us eventually to determine some things about the resulting mentality when the missing factors belong to different groups.

We shall work on these problems at Vineland as rapidly as possible, but they should be studied in normal people as well. It is perhaps true that it would not be possible to go back farther than the living generations; but even so, if careful studies and tests were made of the mental traits in living persons, it would be possible to get the records of two and sometimes three generations, and these records could then be kept and supplemented as the years go by and the newer generations come on. There would thus be laid the basis for most valuable studies later on.

The family histories, that we have secured in connection with our children at Vineland, suggest two or three interesting questions. For instance, there are several families in which alcoholism is strong in several generations. It is possible that we have in these families an unusual appetite for alcohol, which appetite has been transmitted. It looks as though it would not be impossible to eliminate to quite an extent the environmental factor, and so be able to determine whether this was hereditary or not. The same is true of the sexual life. A great many charts show very much sexual immorality: and possibly here we may have, in some cases at least, an unusual development of the sex instinct which has broken over all bounds of conventionality and has shown in different generations. It appears that all of these problems are not only worthy of study, but might yield most important results. The speaker showed graphic charts illustrating the family histories of a number of families. These charts showed the strong inheritance of feeble-mindedness and also illustrated the points made in regard to alcohol and sexuality. Considerable discussion followed.

The Section then adjourned.

F. Lyman Wells,
Secretary.

BUSINESS MEETING.

4 March, 1912.

The Academy met at 8:16 p. m. at the American Museum of Natural History, Vice-President Woodman presiding.

The minutes of the last business meeting were read and approved.

The Recording Secretary reported that Mr. Henry L. Doherty had been elected Treasurer to fill the unexpired term of Mr. Charles F. Cox, deceased.

The Academy then adjourned.

Edmund Otis Hovey,
Recording Secretary.

SECTION OF GEOLOGY AND MINERALOGY.

4 March, 1912.

The Section met at 8:22 p. m., Vice-President Woodman presiding. Fifty members and visitors were present.

The minutes of the last meeting of the Section were read, corrected and approved.

The following programme was then offered:

J. E. Woodman,	Forelands of the Bras d'Or Lakes, Cape Breton Island, Nova Scotia.
Charles P. Berkey,	Is there Fault Control of the Hudson River Course?
V. F. Marsters,	Distribution of Petroleum Deposits in Peru.

SUMMARY OF PAPERS.

Professor **Woodman** illustrated his paper with many photographs showing exceptionally fine views of the topography of the region and the cliffs, bars and spits of the shores. Two peneplain surfaces are to be seen—the higher, characterized by crystalline rocks, and the lower by Carboniferous strata. The hooked spits and loops and bars of recent wave and current work are developed on a scale that is seldom equaled.

Professor **Berkey** discussed the reasons for the usual belief that the straight course of the river is due to fault structure and illustrated this view by the use of Professor Hobbs's map of Atlantic border lineaments. It was then shown that a detailed study of the structural geology of the lower Hudson region shows many strong faults crossing the river obliquely N. E. to S. W. and some much less important running N. W. and S. E., but none of any real consequence running N. and S. or parallel to the Hudson River. It would be considered most extraordinary if a great river like the Hudson should be controlled by small, insignificant faults and pay so little attention to the large fault zones.

Remarks were made by Professor Woodman.

Mr. **Marsters** showed maps and drew sketches of structure and topography. Two belts of oil-bearing strata were described, both Tertiary—a coastal region and an interior region.

The Section then adjourned.

CHARLES P. BERKEY,
Secretary.

SECTION OF BIOLOGY.

11 MARCH, 1912.

By invitation of Professor C.-E. A. Winslow and his colleagues, the Section met at 8:15 P. M. in the Department of Zoölogy of the College of the City of New York, Vice-President Lucas presiding.

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

C.-E. A. Winslow and I. S. Kligler, THE NUMBER AND KINDS OF BACTERIA IN CITY DUST.

C. V. Chapin, THE AËRIAL TRANSMISSION OF DISEASE.

Summary of Papers.

C.-E. A. Winslow and **I. S. Kligler** in their paper presented the results of the examination of about 170 samples of dust from streets, schools, houses and public buildings in New York. The total numbers of bacteria found varied from 150,000 per gram to 145,000,000, averaging from 3,000,000 to 5,000,000 from the indoor dusts and 49,000,000 from the street dust. Spores made up usually less than one-tenth of the total. The count obtained at body temperature was about one-half that at room temperature, averaging from 2,000,000 to 3,000,000 per gram in the indoor dusts and 22,000,000 in the street dusts. *B. coli* was usually present; in the street dust an average of 51,000 per gram was found and in two samples over 100,000, while none showed less than 100. The indoor dust, on the other hand, showed an average of between 1,000 and 2,000. Acid-forming streptococci, such as are characteristic of the mouth, were present to the extent of over 1,000 per gram in three-fourths of the street samples and one-half of the indoor samples. The average for the street samples was about 40,000 per gram; for the indoor samples about 20,000 per gram. The large proportion of these organisms, particularly in the indoor dusts, appears to be significant of buccal pollution.

The paper, which was illustrated by charts and diagrams, was discussed by Dr. Lucas.

Dr. **Chapin** said in abstract: The diffusion of contagion through the room or out-of-doors only was considered, not droplet infection, which does not take place beyond a meter. Bacteriological evidence was not discussed, though the quantitative work of Winslow on sewer air and spray infection was referred to, a work which he is now extending to dust. Epidemiological study and experiment have been rapidly narrowing the list of alleged air-borne diseases. We now know that yellow fever and malaria are never air-borne; experiments have shown that bubonic plague and Mediterranean fever are not. There is no evidence that cholera and typhoid fever are ever air-borne and much that they are not. The spread of influenza out-of-doors does not take place, and perhaps not indoors. The alleged evidence that smallpox virus is air-borne around hospitals is very weak. Careful observation in hospitals has shown that typhus fever, cerebro-spinal meningitis and poliomyeletis do not pass from patient to patient in the same ward. The same is true for uncomplicated scarlet fever and for diphtheria except by contact or close droplet infection. Probably measles and whooping cough, rubella, mumps, chickenpox and smallpox are not air-borne, even in the same room, but further observation may show that such infection may rarely take place.

The paper was discussed by Professors Winslow and Bristol.

The Section then adjourned, the members visiting and examining the laboratories and lecture rooms of the Department of Zoölogy, College of the City of New York.

William K. Gregory,
Secretary.

LECTURE.

15 March, 1912.

F. S. Archenhold: Astronomy, Education and Culture.

SECTION OF ASTRONOMY, PHYSICS AND CHEMISTRY.

18 March, 1912.

Section met at 8:15 p. m., Vice-President Poor presiding.

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

Louis H. Friedburg, Products of Chemical Art.

Summary of Paper.

Dr. **Friedburg** said in abstract: There are three lines along which synthetic chemistry is to-day advancing. First, the production of things found in nature; for example—wintergreen oil, vaniline and camphor. Second, ennobling one substance into another; for example—transformation of cellulose into artificial silk. Third, preparation of substances which are similar to natural substances, but which are not found in nature; for example—celluloid and bakelite.

There are some important discoveries which have been made by accident, such as that of glass 2,600 years ago. The chemist must be alert enough to recognize the value of such accidental discoveries.

The speaker described in a very interesting and entertaining manner the manufacture of parchment paper, mercerized cotton, gun cotton, collodion and artificial silk. He showed on the screen many beautiful examples of the Lumière colored photographs, and the glass caterpillar or spinneret which is used for making the artificial silk fibres. Reaumur in 1784 first suggested the possibility of artificial silk. Celluloid and checkerboard screens for photo-color printing, and, lastly, the making of bakelite or artificial amber (so-called) were explained. Many fine specimens of all substances mentioned were shown.

The Section then adjourned.

F. M. Pedersen,
Secretary.

SECTION OF ANTHROPOLOGY AND PSYCHOLOGY.

25 March, 1912.

Section met in conjunction with the American Ethnological Society at 8:15 p. m., General James Grant Wilson presiding.

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

Robert H. Lowie, Dr. Radosavljevich's Critique of Professor Boas.

Summary of Paper.

Dr. **Lowie** stated that Dr. Radosavljevich had misrepresented Professor Boas on a number of important points. He had entirely misrepresented page 32 of Professor Boas's preliminary report on "Changes in Bodily Form of Descendants of Immigrants."

The "economic" theory scoffed at by Dr. Radosavljevich is a figment of his imagination. What Professor Boas says is that the arrivals during the period following the financial panic of 1893 were under-developed in every direction. When Dr. Radosavljevich reproaches Professor Boas for not studying the effect of American soil and financial panics on the same individuals during a period of time representing the age of his subjects, he shows that he has not the faintest notion of what Boas is discussing in connection with financial panics.

Secondly, Radosavljevich's contention that Boas's own observations do not support his theory of a change of type is a most naïve instance of conceptual realism. The conventional classificatory divisions of head forms have for Radosavljevich an absolute biological value, and unless the head forms of descendants of immigrants fall outside the conventional class of their parents he refuses to admit a change in head form. Dr. Lowie explained what statisticians and biometricians actually mean by a real difference between two series.

In the discussion which followed, several visitors asked for information relating to the nature of Professor Boas's methods, which were explained by Dr. Goldenweiser, who had taken part in the investigation.

The Section then adjourned.

F. Lyman Wells,
Secretary.

BUSINESS MEETING.

1 April, 1912.

The Academy met at 8:25 p. m. at the American Museum of Natural History, Vice-President Woodman presiding.

The minutes of the last business meeting were read and approved.

The following candidates for membership in the Academy recommended by Council, were duly elected:

Active Membership.

Mrs. Henry W. Hardon, 315 West 71st Street.

Associate Membership.

F. F. Hahn, Columbia University.

The Recording Secretary then reported the following deaths:

Edward Russ, an Active Member for 5 years.

John B. Smith, an Active Member for 5 years.

A letter was read from Dr. Hermann Credner thanking the Academy for the honor bestowed upon him by his election to Honorary Membership in the Academy; also an invitation from W. W. Gilchrist, Jr., artist, to the friends of the late Mr. Charles Cox, to view a portrait of the former Treasurer of the Academy at the Folsom Galleries.

The Academy then adjourned.

Edmund Otis Hovey,
Recording Secretary.

SECTION OF GEOLOGY AND MINERALOGY.

1 April, 1912.

Section met at 8:25 p. m., Vice-President Woodman presiding.

The minutes of the last meeting of the Section were read and approved.

The Secretary announced that Mr. Alfred H. Brooks, of the United States Geological Survey, had been secured for the May meeting, at which time he would give a public lecture on the "Geology and Mineral Resources of Alaska."

Dr. Hovey announced that the seismograph which had been presented to the Academy by Mr. Emerson McMillin had reached New York and had been passed by the Custom House.

The following programme was then offered:

Wallace Goold Levison,	Illustrations of Mineral Associations by Means of Color Plate and other Photographs of Opaque Specimens.
A. B. Pacini,	The Metamorphism of Portland Cement. II.
Charles T. Kirk,	Alterations in the Snake River Basalts. (Read by title.)

Summary of Papers.

Mr. **Levison** said in abstract: On a previous occasion the writer presented to the Academy a "Note on Photographs of Minerals for illustrating Books, Papers and Lectures" (Annals N. Y. Acad. Sciences, Vol. XII, pp. 661 and 663). The examples consisted of lantern slides and prints of light-colored mineral specimens of cabinet size mounted on standard size blocks with standard size labels and of microscopic mounts in Rakestraws. (See "Report of Committee on Standard Sizes," N. Y. Acad. of Sciences, 1894.) The writer found it difficult to obtain satisfactory photographs of highly colored minerals in or on colored matrices, as such associations usually afford poor contrasts on ordinary plates.

To produce representations of colored minerals at that time hand-painted or colored lantern slides or prints were the chief expedient.

Some time later the M. A. Seed Dry Plate Co. introduced its G. B. P. R. (green, brown, purple and red) plates, which served better than ordinary plates for lantern slides of certain colored minerals. Thus malachite and prehnite looked well on the green, native copper on the red and rusty or yellow-colored minerals such as the stilbite and calcite from Upper Mt. Clair, N. J., on the brown plates. The entire plate was usually of a tint much similar to that of the specimen, but different parts of the specimen usually developed in tints intermediate between the four possible colors above mentioned, so that pictures on these plates made desirable lantern slides. This method was not applicable to paper prints.

The recently introduced color plates of Lumière, Jougla and Dufay now afford remarkably satisfactory lantern slides of colored minerals of either cabinet or microscopic size.

The methods of production of all these plates were explained, but in the writer's experience the Jougla and Dufay plates seemed to afford slides preferable in transparency and resistance to the heat of the lantern.

Photomicrographs in color of thin sections of rocks and minerals by transmitted polarized light were made by Francois Frank on Lumière plates as early as the year 1907 (Ch. A. Francois Frank, "La Microphotographie en couleur avec les plaques autocrome de M. M. A. et L. Lumière," Comptes Rendus 1er Semestre, T. CXLIV, No. 24, p. 134L, 17 June, 1907).

The first attempt to make photomicrographs, on autocolor plates, of microscopic colored minerals by ordinary reflected light was made by Mr. Frank La Manna, of the Borough of Brooklyn, N. Y., about February, 1911. Mr. La Manna thus photographed on Jougla and Dufay plates he brought from Paris several specimens of microscopic colored minerals mounted in Rakestraws by the writer. (F. La Manna, Exhibit at the Annual Reception of the Department of Microscopy of the Brooklyn Institute, 11 March, 1911.) The deep black interior of the Rakestraws served as a superior black background.

Through the courtesy of Mr. La Manna, the writer received some of these plates upon which he photographed other similar specimens. These photomicrographs, jointly with those of Mr. La Manna, were exhibited before the New York Mineralogical Club in April, 1911, and again at the reception of the Brooklyn Institute's Department of Microscopy, March 9, 1912, and with additions in illustration of this paper. (W. G. Levison, Exhibit at the Annual Reception of the Department of Microscopy of the Brooklyn Institute, March 9, 1912.)

In making these photomicrographs the writer used a lens with a small stop giving a desirable depth of focus, a long bellows, a suitable color screen, long exposure, reflecting screens to soften the shadows and a very rigid adjustment of the apparatus and its supports.

These autocolor plates have likewise afforded the writer very satisfactory lantern slides of colored cabinet specimens. Each picture obtained is a direct positive. Such positives may afford approximately similar copies by the camera or other color plates, but duplicates made directly from the specimen are preferable. They may also, like any colored transparencies, be copied by contact on approximately similar colors, on a paper called Tto color paper by Dr. J. H. Smith, recently introduced from Paris.

Mr. **Pacini's** paper has been published as pages 161-224 of this volume.

Remarks were made by Mr. Johnson and Mr. Price and Mr. Gaines of the Board of Water Supply testing laboratory. Several questions were asked by Professor Arnold of New York University. Remarks were also made by Professor Arnold.

The Section then adjourned.

Charles P. Berkey,
Secretary.

SECTION OF BIOLOGY.

8 April, 1912.

Section met at 8:15 p. m., Vice-President Lucas presiding.

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

Thomas H. Morgan,	Sex-Linked Inheritance in Poultry.
Louis Hussakof,	The Spawning Habits of the Sea Lamprey, *Petromyzon marinus.*
John T. Nichols,	Notes on Cuban Marine Fishes.

Summary of Papers.

Professor **Morgan's** paper has been published as pages 113-133 of this volume.

Dr. **Hussakof** said in abstract: The observations were made on the Nissequoque River at Smithtown, Long Island, June 1 and 2, 1911, while collecting material for an exhibition group of *Petromyzon* for the American Museum. The nests are depressions in the gravel of the river bottom, two or three feet in diameter, and six inches deep at the center. The method of their construction and the general behavior of the specimens of the nest are very similar to those of the Brook Lamprey. But, owing to the large size of this species, all its movements can be minutely observed.

The speaker exhibited a small model of the Lamprey group now under construction in the American Museum of Natural History and also life-size models of adult lampreys. The paper was also illustrated by lantern slides.

Mr. **Nichols** dealt with the results of a brief collecting trip to Cuba and exhibited various specimens. He passed in review some of the Scombriform fishes. The king fish, *Scomberomorus cavalla,* is highly esteemed, but another species, *S. regalis,* is said to be occasionally poisonous. *S. maculatus,* the Spanish mackerel, was not seen. While *regalis* and *maculatus* occupy more or less distinct areas, *cavalla* is abundant both in Florida, with *maculatus,* and in Cuba, with *regalis;* in the speaker's opinion these two last-named species, which are still closely related, have recently become separated through the competition on *cavalla.* Two very widely separated forms, *Arbaciosa rupestris* and *Gobius soporator,* were found inhabiting adjacent rock pools; both were concealingly colored and could have been confused until their distinctive color patterns were noticed.

The paper was illustrated by means of lantern slides.

The Section then adjourned.

William K. Gregory,
Secretary.

SECTION OF ANTHROPOLOGY AND PSYCHOLOGY.

22 April, 1912.

Section met at 8:15 p. m., in conjunction with the New York Branch of the American Psychological Association, R. S. Woodworth acting as Chairman. The afternoon session was held at the Psychological Laboratory, Columbia University, and the evening session was held at the American Museum of Natural History.

The following programme was offered:

Gertrude M. Kuper,	Individual Differences in the Interests of Children.
T. H. Kirby,	Practice in the Case of Children of School Age.
C. D. Mead,	The Age of Walking and Talking in Relation to General Practice.
G. C. Myers,	Sex Differences in Incidental Memory.
A. J. Culler,	Relation of Interference to Adaptability.
E. S. Reynolds, J. T. Gyger and L. L. Winslow,	Experiment in the Catching of Pennies.
D. O. Lyon,	The Optimal Distribution of Time and the Relation of Length of Material to Time Taken for Learning.

Summary of Papers.

Miss **Kuper** said in abstract: That interest plays a very important dynamic role in the educational field is only too evident from such treatises as Dr. Dewey's article, "Interest as Related to Will" and Dr. Montessori's "Pedagogia Scientifica." But interest is a general term and can not have an absolutely universal value for every individual or every subject of thought or desire. Individual interests are as important in the social world as are individual capacities. They should, therefore, be a fruitful field for scientific investigation. The experimental work done with advertisements has brought to light group differences in the preferences of men and women for various appeals. The investigation to be reported was of a like nature, except that it dealt with children.

The formal experiment consisted in asking an individual child to arrange nine pictures in the order in which he liked them best. The nine pictures were chosen to represent nine specific appeals: landscape, children, animals, religion, pathos, sentiment, patriotism, heroism, and action. (They were Cosmos prints and therefore of uniform size and finish.) In all, there were three series of these pictures, each parallel so far as possible with the other two in their appeals. The children numbered over 200, 10 girls and 10 boys for each year's age from 6.5 to 16.5. They were almost entirely attendants of the public schools of New York City and came from quite varied sections of the city.

The results were tabulated according to age differences, broad social distinctions, and nationality. In the last-named case the number of subjects was so limited (10 girls and 10 boys to each of the following nationalities: Irish, French, German, and Italian, and only 9 girls and 8 boys to the Spanish) that the results are not held as significant.

The positive data showed a sex difference in the order of preference for these several appeals. The girls' order was: (1) Religion, (2) patriotism, (3) children, (4) pathos, (5) animals, (6) sentiment, (7) landscape, (8) the heroic, (9) action. The last two were decidedly lowest in the scale and the first three were quite clearly highest for all ages; but the picture representing these nine curves was one of bewildering intersections as the values changed from year to year. The boys' order was: (1) Religion, (2) patriotism, (3) action, (4) the heroic, (5) pathos, (6) animals, (7) sentiment, (8) landscape, (9) children. The boys' chart representing the curves for these appeals showed greater agreement from year to year. Religion and patriotism, the heroic and action, and landscape and children kept rather parallel courses all along the age scale, and no very decided tendencies appeared with progressive age differences. Girls seemed to lose interest somewhat in pictures of children and animals and to take greater interest in the heroic and action pictures. The latter change is explained by the fact that, as the girls increased in school knowledge, they read an historical background into these more or less warlike scenes.

A great sex difference was found in the variability measures, as calculated for the various ages, appeals, social classes, and nationalities. In every case but two, the girls exceeded the boys in their P.E.; and in these two exceptions the boys' P.E. was once greater than the girls' by only 5 per cent., and another time exactly equal to the girls' P.E. The amount of sex difference was, as a rule, anywhere between 12 per cent. and 57 per cent. This held true in every scale, whether according to age, appeals, social class, or nationality. The girls' average P.E. was 1.66; that for the boys was 1.36.

Both girls and boys were least variable about the subjects they liked best, *i. e.,* religion and patriotism; but apart from these appeals there was no correlation of variability with relative likes or dislikes.

It is a noteworthy fact that in range of variability the boys far exceeded the girls. The limits for the boys' P.E. were .82 (patriotism) and 1.60 (landscape), giving a range of difference of 78 per cent.; the limits for the girls were 1.47 (religion) and 1.95 (animals), showing a range of only 48 per cent. In this particular experiment this indicates that boys are very much more agreed about some likes than are girls, and yet quite as varied about others. In other experiments such a range of variability may point to greater individuality of the male sex among themselves while as a group they are relatively homogeneous.

Another sex difference noted was the number of positive dislikes expressed by each sex. The girls gave 161, or 6 per cent. dislikes as against the boys' 65, or 2.4 per cent. Boys seemed to entertain relative indifference toward the appeals at the bottom of the list. The things the girls disliked most were (1) scenes of action suggesting death and (2) pictures showing angry attitudes. The reasons given by the boys for their dislikes were (1) gloomy, indistinct scenes, (2) sentimental pictures, (3) costumes worn by men which were feminine in style or left the figure partly nude, and (4) pictures suggesting illness.

A certain age difference revealed itself in the remarks made by the children about the pictures. The seven and eight year olds showed limited powers of observation. Some detail, and, in landscape scenes, always the human detail, no matter how small, was made the focus of attention to the complete overlooking of the larger subject. Unfamiliar details when pointed out to them received as many different interpretations as there were children. As the children grew older their remarks of both girls and boys. Emotional attitudes, actions and even of the pictures and they drew upon all their known sources for filling in their perceptions. At the ages between 11 and 13 the critical spirit made its first appearance among the girls. Only at fourteen did it occur in the boys' comments. At these ages the emotions prompted the remarks of both girls and boys. Emotional attitudes, actions and even words were ascribed to the pictorial persons. At 15, the remarks became more laconic, but what was said was significant and definite as to the persons, place and action of the picture. This age marked the first signs of hesitation in speaking of the pictures of sentiment. Up to the age of nine the remarks had been very naïve; after that the pictures were dismissed with the phrase, "they're lovers" or "a love picture"; often the characters were named Romeo and Juliet, Paul and Virginia, etc.

In all their comments the girls were far more personal than the boys. The personal pronoun and references to their individual experiences were the usual preface to their statements. With the boys it was quite otherwise; they discussed the picture as an objective thing, independent of their conscious existence. Boys tended to locate scenes in definite historical time and specific geographic places.

The effect of uncertainty about a picture, crudely averaged, was a displacement of about five places toward the lower end of the scale.

Dr. **Kirby** said in abstract: This experiment was conducted to get some information concerning (1) the value of the practise experiment as a method for school work and (2) the value of practise periods of different lengths.

339 fourth year children belonging to 10 different classes took part in the practise, which consisted of adding columns, each of 10 numbers, 0's and 1's not included, as rapidly as was consistent with accuracy, each child competing with his own past record. Seven different sheets of columns of equal difficulty were used (Thorndike's Addition Sheets).

In every case there was one hour of practise, but for different classes this hour was broken into 22½-, 15-, and 6-minute periods, an initial 15-minute period and a final 15-minute period being given to form the basis for determining the gain per cent.

The hour's practise for the 339 children taken as one group resulted in an average gain of 55 per cent.; median gain of 48 per cent. In a similar test with 19 university students, Professor Thorndike found an average gain of 29 per cent., median 33 per cent. from about 53 minutes of practise, and said: "The amount of improvement in this experiment may also add to our confidence that the method of the practise experiments wherein one works at one's limit and competes with one's past record may well be made a regular feature in many school drills. Even if the same length of time produced in children a percentile improvement, only half as great as here, the gain would still probably be far greater than the gain by any of the customary forms of drill."

For the classes which took the hour's practise in 22½-minute periods, there was an average gain of 61 per cent., median 49 per cent.; in 15-minute periods, average gain 55 per cent., median 43 per cent.; in 6-minute periods, average gain 54 per cent., median 44 per cent.

Dr. **Mead** said in abstract: 1. Data.—50 "normal" children (25 boys and 25 girls), averaging less than six years of age, of graduate students of Teachers College and Columbia College. Ages were thrown to the nearest month. Walking means: "To take a step unassisted." Talking means: "To use a word intelligently, *i. e.*, to associate the idea with the object."

Results.—The median "normal" child begins to walk at 13.5 months, with a probable error of 1.06 months. The chances are 999 to 1 that the true median will not differ from the median obtained by more than .66 month. The extreme range is from 11 to 30 months. .90 per cent. of the cases fall between 11 and 17 months. The median "normal" child begins to talk at 15.7 months, with a probable error of 2.83 months. The chances are 999 to 1 that the true median will not differ from the median obtained by more than 1.96 months. The extreme range is from 9 to 25 months. 90 per cent of the cases fall between 10 and 21 months, with 18 months as the mode.

II. *Data.*—145 "schoolable" children (boys and girls) of the Indiana School for Feeble-minded Youth, in reply to the question on the personal descriptive entrance blanks: "At what age did the child commence to walk?" and 92 in reply to the question: "At what age did the child commence to talk?"

Results.—The median feeble-minded child begins to walk at 21.8 months, with a probable error of 7.56 months. The chances are 999 to 1 that the true median will not differ from the median obtained by more than 3 months. The extreme range is from 12 to 72 months. 90 per cent. of the cases fall between 13 and 50 months.

The median feeble-minded child begins to talk at 34.2 months, with a probable error of 12.6 months. The chances are 999 to 1 that the true median will not differ from the median obtained by more than 6.5 months. The extreme range is from 12 to 156 months (only one case going above 108 months). 90 per cent. of the cases fall between 14 and 84 months.

Dr. **Myers** said in abstract: A test was desired wherein the thing to be remembered should be merely incidental and where the focus of the subject's attention should be directed away from the facts to be called for after the exposure of the stimuli, but where these facts would have to enter, wholly or in part, into the experience of the subject. To this end a list of six simple words were used as stimuli. The subject was told that he would be given a spelling test and he was led to believe that it would be a real test in speed and accuracy of spelling.

A practise test with digits was given for three successive times before the real test began, to delude the subject as to the purpose of the experiment. A dozen or more digits were pronounced at random so rapidly that the subject could scarcely keep up in writing them. In the midst of this series of digits the experimenter, without any warning, gave the signal for the subject to turn the page upon which he was writing, and continued to pronounce digits at the same speed. The subject was told that the words would be given in the same manner, but not quite so rapidly. The following words were then pronounced: angel, pickle, dirt, busy, onion, women. The last word was pronounced in such a manner that another word was expected by the subject, but the signal, "turn," was given instead, and the subject was told to write as many of these words as he could remember, to place them in the order in which they had been given, and to indicate by a line the place for each omitted word. The time each individual required to reproduce the words was recorded by a stop-watch.

After testing over 100 individuals the writer applied the test to groups of college, normal-school and public-school subjects. Aside from immediate reproduction, records were secured after various intervals, ranging from ½ hour to 3 months. In all such cases a practice test of rapid folding of papers was added. After the words were pronounced the papers were promptly collected and the experimenter left the room. The subjects thought the work was ended, but at various times the experimenter reappeared and asked for the reproduction. The time for all group reproduction was limited to 1½ minutes.

The best results were secured immediately after presenting the stimuli. Practically the same efficiency was shown for the reproduction after 6 hours as for that after ½ hour. But there was a decided fall after 7 days and a still greater fall after 3 months.

No appreciable difference was shown in efficiency between the lower grades and the college students for immediate reproduction; but after various intervals there was a gradual decrease in efficiency with age.

Of the 1,515 subjects, 757 females and 758 males, only 29 of the former and 18 of the latter reproduced the six words in exact order.

In all grades the females were markedly superior to the males, both for the number of words remembered and for order. They had a higher central tendency and were more variable than the males in the 5th, 6th, 7th, and 8th grades, while for the other groups the males were more variable.

108 other subjects were tested with 10 letters and digits. Here the girls answered more, but the boys were better for order.

Mr. **Culler** said in abstract: The purpose of this experiment was twofold: to determine the effect of differently distributed practise series upon learning given material; and to make observations upon the learning process in general.

The material to be learned was the path from the beginning to the end of the Hampton Court maze. The paper (8 by 6 inches) on which the maze was printed, was affixed to a board. Over it was placed a large circular piece of cardboard, easily movable, having in the center a small opening (5/8 to 11/16 inch) through which extended a pencil to mark the course of the subject's movement. At no time could the subject see more of the maze than the part visible through the opening. At the beginning of the experiment the subject was thus instructed: Pencil is now at the entrance to the maze; keep on moving until you reach the end. Never cross a line; always keep to an open path. Mazes are all the same and will be placed in the same position.

At each trial the time was recorded and number of errors was counted and recorded. To each subject were given 12 trials. Subjects were divided into 6 groups as follows: 12 trials at one time, 6 on 2 successive days, 4 on 3 days, 3 on 4 days, 2 on 6 days and 1 on 12 days. There were 5 men in each group except the last, in which were 3. With regard to time of day, subjects were divided into two groups: one group each day for the required number of days, after lunch (1–2 P. M.): the second group each day after dinner (7–8 P. M.). In comparing men of the two groups no account was taken of this slight difference, as it was considered practically negligible. Good light was uniformly provided. The interval between successive trials of a subject at the same sitting was 30–40 seconds.

Subjects were all graduate students, age from 22 to 28.

Three classes of errors appeared: Wrong choice between alternative courses, retracing when on right course, and (accidentally) crossing a line. The first kind are major errors (value 1) and the other two kinds minor (value ½). These are arbitrary values for computing results. The major errors were counted as follows: There are 6 (or 7, depending upon the course taken) places where choice must be made between alternative paths of which only one is right. Each time the subject moved from one of these places in a wrong path, *i. e.*, away from the goal, it was counted one error. Errors of retracing when on the right path were usually small and due to defective attention or eyesight—subject either thought he had accidentally passed an opening and moved back to see, or on coming to a turn failed to notice the opening and thought he had run into a blind alley.

The results are as follows:

I. Table of Absolute Time and Error Values Attained in Each Group

(The different groups are indicated thus: One—12, etc.; the word indicates the number of trials each day, the figure the number of successive days. The two columns show the average of number of seconds consumed and number of errors made in the last three trials in each group; thus showing the relative standing of groups at end of practice period. The figures in parentheses show relative position.)

	Time, Per Cent.	Errors, Per Cent.
One—12	50 (3)	4.8 (4)
Two—6	61 (5)	5.2 (5)
Three—4	59 (4)	3.2 (3)
Four—3	39 (1)	.9 (1)
Six—2	75 (6)	5.5 (6)
Twelve—1	48 (2)	3.0 (2)

II. Table of Percentage Gains

(In each case the percentage represents the ratio between the average of first three trials and last three trials in the same group. This table is intended to show improvement of each group irrespective of absolute values attained.)

	Time, Per Cent.	Errors, Per Cent.
One—12	210.0 (4)	147.9 (5)
Two—6	253.0 (3)	161.5 (4)
Three—4	195.0 (6)	302.0 (1)
Four—3	341.0 (2)	218.5 (3)
Six—2	206.6 (5)	125.3 (6)
Twelve—1	368.7 (1)	236.6 (2)

(It must be said that the results of Six—2 were vitiated by the professed indifference of one subject, because of which both time and errors for the last few trials in that group are abnormally high.)

The results seem to point to the following conclusions: In general, outside the Six—2 group, the One—12 and Two—6 groups made the lowest absolute records and also least improvement; this apparently indicates that the learning period was too prolonged, with insufficient practise at any one time. On the other hand, the Twelve—1 and Four—3 groups show in general the highest absolute records and greatest improvement. Here the practise was more thorough each time and not so prolonged. The curve of greatest regularity is the Four—3 curve. The three groups, then, in which practise periods were longer and confined to a few days show better results than the three in which practise periods are shorter and prolonged over 4–12 days. The application to learning any material would seem to be that better results are secured by a few more prolonged or persistent periods of study repeated perhaps for several days than shorter periods prolonged over a greater number of days.

Some observations were made on individual methods of learning which can not be included here.

Messrs. **Reynolds, Gyger** and **Winslow.** The authors said in abstract: The experiment had two aims: (1) To investigate the learning process. (2) To find what transfer, from the right hand to the left, if any, would be shown.

Three subjects took part in the experiment which follows. It was carried on in two series: (1) That in which the subjects caught the pennies, two at a toss, palm of the hand down. (2) That in which they caught three. The first series was of 7 days' duration; the second, 10 days'. The time for tossing was from 1 P. M. to 2 P. M. on Mondays and Wednesdays. Conditions were as nearly constant as possible, the same room being used throughout the experiment. In the case of the two-penny series, the subjects caught for 10 trials and then rested for 10. In the three-penny series two subjects caught at the same time, the third subject resting. In the first case, score was kept by the two unemployed subjects in turn; in the second case, by the one unemployed subject.

Certain conditions influencing accuracy were noted, among which are the following: Some parts of the room were more conducive to accurate catching than others, that nearest the window being the most favorable. The pennies could be caught with most accuracy if no objects were in front of the subject to distract his attention. The tossing, when carried on before a blank, light-colored wall, was most successful. An increase in confidence and in accuracy resulted when a window was opened to admit new air. An interruption, as that caused by another person entering the room, was followed by a corresponding fall in score. The subject, by counting to himself his successful tosses, was stimulated to a better score. The nervous feeling of haste as well as nervousness caused by outside matters of importance to the subjects (such as pressure of work) tended rather to increase than to diminish their scores.

Each subject discovered and followed his own methods of tossing. After finishing the two series, the subject who had followed the method of throwing his pennies high into the air was able to catch an additional penny (making four in all) with very little effort. The other subjects tried this continually and failed, their hands striking the floor before the fourth penny was reached. The quick shutting of the hand was an important factor. One subject was materially helped by thinking of the word "grab" previous to each trial. In some instances, the second penny would be caught and lost, the first and third being retained. Although occasionally a subject would catch all three successfully without knowing it, yet the tossing can not be said to have become automatic.

The progress in learning was unsteady. Yet in each case there was a gradual advance, noticeable particularly in the beginning. A warming-up period was universally experienced by each subject at the beginning of each day's practise.

In the second series, a transfer test was tried with the left hand before and after the practise series. This showed a considerable increase in ability to catch with the left hand.

AMOUNT OF TRANSFER CATCHES

Subject.	Before Test.	After Test.	Per Cent Gain.
1	3	14	466⅔
2	11	32	290+
3	1	29	2900
Total gain	15	75	500

Mr. **Sax** said in abstract: Although art and science are widely separated, they may co-operate in art education. Prevailing methods are indirect, depending upon a never certain transfer of training. During the three years the average student spends at art school, his course is as follows: Casts and still life in charcoal; still life in color; anatomy and perspective as formal subjects; the figure in charcoal; some composition, and, finally, painting the head and figure in oils.

Results show little transfer; for example, compositions show little knowledge of anatomy or perspective. Charcoal and oils have few identical elements in substance or procedure; in fact, specific habits formed in mastering charcoal often act preclusively when the student attempts to paint. Students who can draw, but not paint; construct, but not compose, or are draughtsmen, but not colorists, and their opposites are in the overwhelming majority.

Experiments now under way on the learning process as applied to painting seem to show that (*a*) preparation in charcoal and still life is unnecessary in painting figures; (*b*) efficiency depends largely upon correct analysis; (*c*) muscular coordination plays a minor part; (*d*) a direct method and generalized idea of procedure are essential and (*e*) the control of attitude is most important.

Dr. **Lyon** said in abstract: This paper was divided into two parts, it being in reality a discussion of two distinct questions: (1) "The Distribution of Time in Relation to Economy in Learning and Retention";

and (2) "The Relation of Length of Material to Time Taken for Learning." Concerning the first of these, it was shown that in estimating *economy,* not only must we consider the *time spent,* but the degree of *retention* as well. It was shown that individuals differ greatly, and that where one could learn a set of ten stanzas in less time by the continuous method (*i. e.,* doing the work in "one sitting"), another individual could lower his total time by dividing the time spent into several periods, *e. g.,* by spending 5 minutes per day. With but three exceptions retentiveness was decidedly better by the divided-time-method. This was notably the case with nonsense-syllables and poetry. The most general statement that can be made, taking all materials and methods of presentation into consideration, is that the most economical method is to distribute the readings over a rather lengthy period—the intervals between the readings being in arithmetical proportion. For example, with one individual in memorizing a poem of twenty stanzas the highest retentiveness was obtained by distributing the readings as follows: 2 hours, 8 hours, 1 day, 2 days, 8 days, 16 days, 32 days, etc. The practical bearing of the results obtained on education in general was then considered. The above individual found that the most economical method for keeping material once memorized from disappearing was to review the material whenever it started to "fade." Here also the intervals were found to be, roughly speaking in arithmetical proportion. For similar reasons the student is advised to review his "lecture-notes" shortly after taking them, and if possible, to review them again the evening of the same day. Then the lapse of a week or two does not make nearly so much difference. When once he has forgotten so much that the various associations originally made have vanished, a considerable portion of the material is irretrievably lost.

2. *The Relation of the Length of Material to Time Taken for Learning.*—Tables were presented to show that the relation depended almost wholly upon the division of the time spent in learning, *i. e.,* the distribution of the time intervals. In other words, the relation, or *ratio,* depends upon the method used in memorizing. Only three methods were considered: The "continuous" or "mass" method; the once-per-day method; and the once-per-week method. Up to a certain point, with some individuals, when digits were used as material, the time varied directly as the square of the number of digits, when the continuous method was used. By the once-per-day method, however, the time varied, roughly speaking, directly as the length of the material. It was shown that in order to get the best results the same subject should take all the various lengths of material used, and that it would be unfair to dis-

tribute the varying lengths among different subjects. As only one method can be tried at a time, an experiment of this nature must needs extend over a period of several years. In the case of prose, by the once-per-day method, 500 words were memorized in as few days as the 95-word passage. The time may therefore be said to vary directly as the length of the passage. The same holds true for digits and nonsense-syllables, but not to so great a degree; for the number of days needed for 200 nonsense-syllables was considerably greater than that needed for 20. By the "continuous" method, however, we observe that where the 100-word passage was memorized in 9 minutes, the 500-word passage took 52 minutes—nearly 6 times as much time being required, although the passage is only 5 times as long. This is much more strikingly shown when we examine the curve obtained for the digits. Here we see that although it took only 5 minutes to learn 24 digits, it took 2 hours and 34 minutes to learn 200—more than 31 times as long instead of 8. In short, it is obvious that the once-per-day method is—to say nothing of giving a far superior retention—far more economical than the "continuous" method. This is especially so for material memorized by motor associations such as nonsense-syllables or digits.

The Section then adjourned.

F. Lyman Wells,
Secretary.

BUSINESS MEETING.

6 May, 1912.

The Academy met at 8:15 p. m. at the American Museum of Natural History, President McMillin presiding.

The minutes of the last business meeting were read and approved.

The Recording Secretary reported the deaths of the following members:

Col. John Jacob Astor, an Active Member for 18 years, lost with the Titanic.

Mr. Isidor Straus, an Active Member for 6 years, lost with the Titanic.

Col. John Weir, a Life Member for 5 years, lost with the Titanic.

Mr. George Borup, an Active Member for 4 months.

The Recording Secretary spoke of the great loss to the Academy, the Museum and the scientific world at large entailed by the death of Mr. Borup, who was to have been the leader of the Crocker Land Expedition organized under the auspices of the American Museum of

Natural History and the American Geographical Society for the purpose of arctic exploration during the years 1912–1914.

The Academy then adjourned.

Edmund Otis Hovey,
Recording Secretary.

SECTION OF GEOLOGY AND MINERALOGY.

6 May, 1912.

Section met at 8:30 p. m., Vice-President Woodman presiding, about 150 members and visitors being present.

The following papers were read by title:

Neil E. Stevens, Notes on the Structure and Glaciation of Overlook Mountain.

George F. Kunz, The Gem-bearing Pegmatites of Lower California.

The meeting was then given over to the following public lecture:

Alfred H. Brooks, Geology and Mineral Resources of Alaska.

Mr. Brooks has been in charge of Alaskan exploration for the United State Geological Survey for the last ten years or more. No one is more intimately acquainted with the geography, geology and resources of that country. The lecture was illustrated with lantern slides, maps and charts.

The Section then adjourned.

Charles P. Berkey,
Secretary.

LECTURE.

7 May, 1912.

James F. B. Bowles: Sanitation of the Panama Canal.

SECTION OF BIOLOGY.

13 May, 1912.

Section met at 8:15 p. m., Vice-President Lucas presiding.

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

R. D. O. Johnson,	Note on the Habits of the Climbing Catfish (*Arges marmoratus*) from the United States of Colombia. (Read in abstract by the Secretary.)
Bashford Dean,	On the Changes in the Behavior of the Eel (*Conger malabaricus*) during its Transformation.
Bashford Dean,	Do Developing Embryos Give Real Clues as to Lines of Descent?
William K. Gregory,	Notes on Certain Principles of Quadrupedal Locomotion and on the Mechanism of the Limbs of Hoofed Animals.
F. F. Hahn,	On the Dictyonema Fauna of Navy Island, New Brunswick. (Read by title.)

Summary of Papers.

Mr. **Johnson's** paper is published as pages 327–333 of this volume.

Professor **Dean** said in abstract: When at Misaki, Japan, the speaker had made observations upon the structure and behavior of a living leptocephalus larva which was kept alive in an aquarium for over three weeks, during this time undergoing its metamorphosis. Especially interesting is the rapidity with which the behavior of the young eel changes from day to day in its methods of swimming and resting, response to stimuli, etc. The speaker suggested that these marked differences in behavior in successive stages were correlated with kaleidoscopic changes in elements of the central nervous system; that when more fully known this would probably afford a suggestive case of parallelism between psychic reactions and neurological conditions. The paper was illustrated by drawings and diagrams.

Professor **Dean** in his second paper said in abstract: After reviewing the history of the question and touching upon the modern reaction against the extreme views of Haeckel the speaker endeavored to show that a comprehensive study of the anatomy and embryology of ganoid and teleost fishes in the light of paleontological data gave strong evidence in the affirmative.

The Secretary gave an abstract of a communication from Dr. P. Bachmetjew, of Sofia, relating to the physiology of *"Vesperugo pipistrellus"* and *"Miniopterus schreibersii."* In some cases these bats have been thawed out and the heart action had resumed even after the body had been cooled to —7° Cent. below the body temperature.

The Section then adjourned.

William K. Gregory,
Secretary.

SECTION OF ASTRONOMY, PHYSICS AND CHEMISTRY.

20 May, 1912.

Section met at 8:15 p. m., in the Doremus Lecture Room of the Chemistry Building of the College of the City of New York, Professor Poor presiding.

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

Charles Baskerville, Tungsten.

Summary of Paper.

Professor **Baskerville** pointed out that tungsten at one time was hardly mentioned in text books, but that now it is a substance of considerable importance. It was discovered in tin-ore by Carl W. Scheele in the year 1781. In 1848, tungsten salts were used for fixing colors in cotton, and, in 1857, the fireproofing of draperies by tungsten was proposed. Tungsten is used in making bronze and steel. Tungsten steel retains its temper even when red hot and is better than the best carbon steel known. The rims of car wheels are made of tungsten steel.

The speaker then gave an interesting account of the invention and development of tungsten lamps. He spoke at some length of the very great practical difficulties that had to be overcome owing to the fact that the tungsten filaments were brittle. Finally, however, this was overcome so that now the tungsten incandescent lamp is the best one on the market.

The Section then adjourned.

F. M. Pedersen,
Secretary.

BUSINESS MEETING.

7 October, 1912.

The Academy met at 8:25 p. m. at the American Museum of Natural History, President McMillin presiding.

The minutes of the last business meeting were read and approved.

The Recording Secretary reported the following deaths:

Ferdinand Zirkel, Honorary Member for 8 years.
Jules Henri Poincaré, Honorary Member for 12 years.

The Academy then adjonrned.

Edmund Otis Hovey,
Recording Secretary.

SECTION OF GEOLOGY AND MINERALOGY.

7 October, 1912.

Section met at 8:30 p. m., Vice-President Woodman presiding, about 35 members and visitors being present.

The minutes of the last meeting of the Section were read and approved.

Before the announced papers were called for the chairman asked Professor J. F. Kemp to give some account of his recent trip to Panama. A first-hand general account of his experiences and geologic observations was given. Questions were asked by members of the Section.

The following programme was then offered:

D. W. Johnson, The Westward Trip of the Transcontinental Excursion of the American Geographical Society.

George H. Girty, Geologic Age of the Bedford Shale of Ohio.

Summary of Papers.

Dr. **Johnson** gave an interesting account of the make-up of the party, the method of travel, the places of greater interest and some of the special features to which most attention was given.

Dr. **Girty's** paper was read in part by Professor Grabau and its bearings were commented upon. It has been published as pages 295-319 of this volume.

The Section then adjourned.

Charles P. Berkey,
Secretary.

SECTION OF BIOLOGY.

14 October, 1912.

Section met at 8:15 p. m., Vice-President Lucas presiding.

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

Roy W. Miner, Typical Marine Invertebrate Association from Woods Hole to Casco Bay.

Roy C. Andrews, An Exploration of Northeastern Korea.

Summary of Papers.

Mr. **Miner** described and illustrated a series of typical invertebrate faunal complexes or associations of the eastern Atlantic coast. He gave views of many beautiful models and faunal groups which had been mode for the American Museum, illustrating ecological relations and the dominance of certain groups in particular localities.

Mr. **Andrews** gave an account of an exploration made for the American Museum of Natural History in a territory not hitherto studied by zoölogists.

The Section then adjourned.

William K. Gregory,
Secretary.

SECTION OF ASTRONOMY, PHYSICS AND CHEMISTRY.

21 October, 1912.

Section met at 8:30 p. m., Vice-President Poor presiding.

The minutes of the last meeting of the Section were read and approved.

Professor Charles Lane Poor was nominated for Vice-President of the Academy and Chairman of the Section for 1913.

Professor F. M. Pedersen was elected Secretary.

The Committee on the future of the Section, consisting of Professors Poor, Trowbridge and Pedersen then made its report, which was referred to the Council for consideration.

F. M. Pedersen,
Secretary.

SECTION OF ANTHROPOLOGY AND PSYCHOLOGY.

28 October, 1912.

Section met in conjunction with the American Ethnological Association at 8:15 p. m., General James Grant Wilson presiding, about 128 members and visitors being present.

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

Franz Boas, A Year in Mexico.

Summary of Paper.

Professor **Boas** gave an outline of the work of archeological excavation and linguistic research conducted by him during his stay in Mexico. His lecture was illustrated by numerous stereopticon slides showing especially pottery found in different layers in the Valley of Mexico.

The Section then adjourned.

F. Lyman Wells,
Secretary.

BUSINESS MEETING.

4 November, 1912.

The Academy met at 8:30 p. m. at the American Museum of Natural History, Vice-President Woodman presiding.

The minutes of the last business meeting were read and approved.

The Recording Secretary reported the following death:

Morris Loeb, an Active Member and Fellow for 20 years.

The preparation of a suitable minute for the records of the Academy was referred to Professor J. J. Stevenson and Dr. E. O. Hovey.

Announcement was made from the Council of the engagement of Dr. Alexis Carrel, to give an address before the Academy on 11 November, regarding his recent experimental work in physiology and of Professor Hugo de Vries for an address upon experimental evolution to be delivered 6 December.

The Academy then adjourned.

Edmund Otis Hovey,
Recording Secretary.

SECTION OF GEOLOGY AND MINERALOGY.

4 November, 1912.

Section met at 8:45 p. m., Vice-President Woodman presiding, 23 members and visitors being present.

In the absence of Secretary Berkey, Dr. Hovey was elected Secretary *pro tem.*

The minutes of the last meeting of the Section were read and approved.

On motion duly made and seconded, Professor J. E. Woodman was nominated chairman of the Section and Vice-President of the Academy for the year 1913.

Professor Berkey expressed the earnest wish that he be relieved of the secretaryship which he had held five years. The Section acquiesced in the request and passed a most cordial vote of thanks to him for his long, faithful and efficient services, which have contributed so much to the success of the Section. Professor C. T. Kirk of the Normal College of the City of New York, was then nominated Secretary of the Section for 1913 and unanimously elected.

The chairman then appointed Professor J. F. Kemp, Dr. George F. Kunz and Dr. E. O. Hovey to serve with himself as a committee, in response to a request of the Council, to consider the condition of the Section and to make recommendations for its future work, this Committee to report to the Council.

The Secretary *pro tem* then read a letter from R. B. Earle of the Department of Geology, New York University, asking for a grant of $200 to assist him in carrying on research work on the origin and history of certain types of interbedded iron ores. On motion, this application was approved and referred to the Committee on Grants from Research Funds for consideration.

The following programme was then offered:

F. S. Hintze,	The Fossils and Horizon of the Drift Pebbles.
Marjorie O'Connell,	Present Opinions on the Habits of the Eurypterids.
A. W. Grabau,	Was there a Former Goat Island at Niagara Glen?

Mr. Hintze's paper was discussed by Professor A. W. Grabau, Professor J. F. Kemp, Mr. B. E. Dodge and Professor D. S. Martin.

Miss O'Connell's paper was discussed by Professor Grabau.

Summary of Paper.

Professor **Grabau** said in abstract: Foster's Flat below the whirlpool of Niagara and the topography and cross section of the gorge show that the falls of Niagara were once localized there in the same style as is now the case at Goat Island. The same kind of development of river work is well illustrated also at the falls of the Genesee.

The paper was discussed by Professor D. W. Johnson, who cited what is probably a similar case from near St. Anthony's Falls, Minnesota, of the Mississippi River.

The Section then adjourned.

Edmund Otis Hovey,
Secretary pro tem.

SECTION OF BIOLOGY.

11 November, 1912.

On this occasion the Section of Biology co-operated with the Academy as a whole and with the American Museum of Natural History in welcoming Dr. Alexis Carrel, recipient of the Nobel Prize in medicine, 1912, who gave a lecture in the large auditorium, entitled "Results of the Suture of Blood Vessels and the Transplantation of Organs," about 800 persons being in attendance. After the lecture an informal reception, attended by the officers, members and friends of the Academy was held in honor of the lecturer.

William K. Gregory,
Secretary.

SECTION OF ASTRONOMY, PHYSICS AND CHEMISTRY.

18 November, 1912.

Section met at 8:15 p. m., Vice-President Poor presiding.

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

Albert B. Pacini, The Distribution of Ferric Chloride between Ether and Aqueous Hydrochloric Acid at 25° C.

Charles Lane Poor, The Cause of the Tides.

SUMMARY OF PAPERS.

Dr. **Pacini** gave a study of the distribution of ferric chloride under the conditions which obtain in the use of Rothe's method for the determination of aluminum, nickel and other metals in steel, the mixed chlorides in hydrochloric acid solution being shaken out with ether which removes the greater portion of the ferric chloride. No decisive knowledge was gained regarding the state of molecular aggregation of the ferric chloride in the ether solution insomuch as data concerning the degree of disassociation of ferric chloride in aqueous solution are not at present available.

Graphical treatment of the constants obtained yields a curve of two distinct sections: in low concentrations up to about 0.38 mols per liter in the ether layer, a straight line; above this point a parabola satisfying the equation $(C_E - .38)^2 = KC_W$, where $K = +1.8$.

The application of the results to analytical separation lies in the fact that the percentage of iron extracted from a hydrochloric acid solution by shaking out with ether is greater relatively as the concentration is lower, that is to say, the more dilute the original hydrochloric acid solution of iron, the nearer complete is the extraction of ferric chloride therefrom by ether.

Professor **Poor** gave a brief outline of the theories of the tides as developed by La Place, Darwin and others, and contrasted these older theories with recent investigations and theories of Dr. Harris, of the United States Coast and Geodetic Survey. Until the researches of Dr. Harris appeared, the tides were considered as a world phenomenon, and primarily due to a large wave which originates in the Pacific Ocean and travels around the world at varying speeds, due to the depth of the oceans. This wave was supposed to take some fifty hours to travel from the Pacific around Cape Horn to the shores of New York. Dr. Harris considers the tides as purely local phenomena; the tide of each ocean basin is primarily due to a standing wave or oscillation originating in that basin and practically independent of the oscillations or tides in other basins. The tides at New York and the Atlantic Coast, under this theory, originate in the North Atlantic basin and are wholly independent of the tides in the Pacific and Indian Oceans.

The Section then adjourned.

F. M. PEDERSEN,
Secretary.

SECTION OF ANTHROPOLOGY AND PSYCHOLOGY.

25 November, 1912.

Section met in conjunction with the New York Branch of the American Psychological Association, Dr. R. S. Woodworth acting as chairman. The afternoon session was held at the Psychological Laboratory, Columbia University, at 4:10 P. M. and the evening session was held at the American Museum of Natural History at 8:15 P. M.

The following programme was offered:

F. Krueger,	Different-Tones and Consonance.
Raymond Dodge,	The Attempt to Measure Mental Work as a Psycho-Dynamic Process.
Robert M. Yerkes,	The Psychology of the Earthworm.

The Section then adjourned.

F. Lyman Wells,
Secretary.

BUSINESS MEETING.

2 December, 1912.

The Academy met at 8:15 P. M. at the American Museum of Natural History, President Emerson McMillin presiding.

The following candidates for membership in the Academy, recommended by Council, were duly elected:

Active Membership.

D. W. Johnson, Columbia University.

Associate Membership.

Marjorie O'Connell, 616 West 182nd Street.

The Academy then adjourned.

Edmund Otis Hovey,
Recording Secretary.

SECTION OF GEOLOGY AND MINERALOGY.

2 December, 1912.

Section met at 8:20 P. M., President McMillin presiding.

The meeting was devoted to the following public lecture:

Harry Fielding Reid, The Seismograph and What it Teaches.

Professor **Reid** described the characteristics of the seismograph, which has now been sufficiently perfected to record strong earthquakes occurring at the antipodes. The revelations of the instrument and problems awaiting solution were discussed and what happens at the time of an earthquake was explained. The lecture was illustrated with lantern slides.

The Section then adjourned.

Charles P. Berkey,
Secretary.

LECTURE.

6 December, 1912.

(In co-operation with the American Museum of Natural History.)

Hugo de Vries, Experimental Evolution.

SECTION OF BIOLOGY.

9 December, 1912.

Section met at 8:15 p. m., Professor Henry Fairfield Osborn presiding.

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

C.-E. A. Winslow, A Museum of Living Bacteria.
A. J. Goldfarb, The Influence of the Nervous System upon Growth.
A. J. Goldfarb, A New Method of Fusing Eggs of the Same Species.

Summary of Papers.

Dr. **Winslow** said in abstract: The American Museum of Natural History is the first museum of its kind to recognize that the relation between man and his microbic foes is fundamentally a problem in natural history and a problem of such interest and importance as to warrant the creation of a special Museum Department of Health. The prime function of this department is of course to present in the form of effective exhibits the main facts about the parasites which cause disease, their life history, the conditions which favor their spread to man, their relations to intermediate insect hosts and the means by which mankind may be protected from their attacks. In connection with this work of public exhibition there seemed to be a unique opportunity for maintaining, as a sort of study collection, a museum of living bacteria for the benefit of working laboratories all over the country. American bacteriologists have heretofore been compelled to send to Vienna for authentic stock cultures, and many important type strains have been lost because the laboratories in which they were isolated had no facilities for keeping them permanently under cultivation. The authorities of the Museum were quick to appreciate the importance of the public service that could thus be rendered to those engaged in bacteriological teaching and research and early in 1911 endorsed the establishment of such a collection and bureau for the distribution of bacterial culture. A circular was sent out, to which the various laboratories quickly responded by sending in the cultures in their possession. On December 1, 1912, the collection included 578 strains representing 374 different named types and including most of the important pathogenic and non-pathogenic forms which have been definitely described.

During the period of somewhat less than two years, from January 1, 1911, to December 1, 1912, the laboratory distributed to 122 different colleges and research laboratories of the United States and Canada 1700 different cultures, in every case without charge. It is the policy of the Department to send cultures free to all teaching laboratories of college and university grade and to all research laboratories, whether cultures are sent to it in return or not. Many cultures have been called for by teaching laboratories for use in their class work. The most important service the laboratory has been able to render, however, has been in furnishing authentic cultures to investigators who have been making a study of certain special groups and the published papers which have resulted, in which various detailed characters of the museum types are described, of course greatly increase the value of the collection.

The paper was discussed by Professor Osborn.

Dr. **Goldfarb** described a series of experiments upon certain annelid worms (*Amphinoma Lumbricus*) which showed that the presence of the central nervous system was not essential for growth and regeneration.

Dr. **Goldfarb**, in his second paper, described a method of fusing embryos and larvae of the sea urchin (*Toxopneustes*). After fertilizing the eggs they were placed in sea water to which enough 5/8 molecular Na Cl was added to make a solution of 35 to 75 per cent. The eggs were left in this solution about six hours and were then transferred to normal sea water. The unfused larvae floated to the surface, the fused ones, which were obtained in great numbers, remained at or near the bottom.

The Section then adjourned.

William K. Gregory,
Secretary.

ANNUAL MEETING.

15 December, 1912.

The Academy met in Annual Meeting on Monday, 16 December, 1912, at the Hotel Endicott, at the close of the annual dinner, President McMillin presiding.

The minutes of the last Annual Meeting, 18 December, 1911, were read and approved.

Reports were presented by the Corresponding Secretary, the Recording Secretary, the Librarian and the Editor, all of which, on motion, were ordered received and placed on file. They are published herewith.

The Treasurer's report showed a net cash balance of $1,555.51 on hand at the close of business, 30 November, 1912. On motion, this report was received and referred to the Finance Committee for auditing.

The following candidates for honorary membership and fellowship, recommended by Council, were duly elected:

Honorary Members.

Iliya Metchnikof, Biologist and Bacteriologist, Pasteur Institute, Paris, France, presented by Dr. C.-E. A. Winslow.

Sir John Murray, Oceanographer, Edinburgh, Scotland, presented by Dr. F. A. Lucas.

Sho Watasé, Zoölogist, Imperial University of Tokio, Japan, presented by Prof. Henry E. Crampton.

Frank D. Adams, Geologist, McGill University, Montreal, presented by Prof. James F. Kemp.

George E. Hale, Astronomer, Solar Observatory, California, presented by Dr. John Tatlock.

Fellows.

Felix Arnold, M. D., 824 St. Nicholas Avenue, New York.
Dr. R. B. Earle, New York University, New York.

Prof. Jesse E. Hyde, School of Mining, Kingston, Ontario.
Prof. D. W. Johnson, Columbia University, New York.
Dr. A. B. Pacini, 275 West 140th Street, New York.
Mr. V. Stefánsson, American Museum of Natural History, New York.
Dr. F. Lyman Wells, McLean Hospital, Waverley, Massachusetts.

The Academy then proceeded to the election of officers for the year 1912. The ballots prepared by the Council in accordance with the By-laws were distributed. On motion it was unanimously voted that Dr. Stevenson cast one ballot for the entire list nominated by the Council. This was done and they were declared elected, more than the requisite number of members and fellows entitled to vote being present:

President, EMERSON McMILLIN.

Vice-Presidents, J. EDMUND WOODMAN (Section of Geology and Mineralogy), W. D. MATTHEW (Section of Biology), CHARLES LANE POOR (Section of Astronomy, Physics and Chemistry), W. P. MONTAGUE (Section of Anthropology and Psychology).

Corresponding Secretary, HENRY E. CRAMPTON.

Recording Secretary, EDMUND OTIS HOVEY.

Treasurer, HENRY L. DOHERTY.

Librarian, RALPH W. TOWER.

Editor, EDMUND OTIS HOVEY.

Councilors (to serve 3 years), FREDERIC A. LUCAS, R. S. WOODWORTH.

Finance Committee, EMERSON McMILLIN, FREDERIC S. LEE, G. F. KUNZ.

At the close of the elections, Mr. Emerson McMillin gave his address as retiring President, in which, after reviewing the present condition of the Academy as derived from conference with a large number of the men who have long been active in carrying on its various lines of work, he made several recommendations regarding plans which might be adopted for enlarging the usefulness and interest of the organization and its meetings.

Mr. V. Stefánsson then gave a most interesting summary account of the expedition which he and Dr. R. M. Anderson made along the Arctic coast of western North America, from Point Barrow to Coronation Gulf during the years 1908-1912 inclusive. At the close of his lecture, Mr. Stefánsson outlined the plans of the second expedition which he is now organizing for geographical and ethnological work on Victoria, Banks and Prince Patricks Islands in the years 1913-1916 inclusive, and indicated the manner in which his expedition and the Crocker Land Expedition will supplement each other's work.

The Academy then adjourned. EDMUND OTIS HOVEY,
Recording Secretary.

REPORT OF THE CORRESPONDING SECRETARY.

We have lost by death during the past year the following Honorary Members:

Sir George H. Darwin, elected 1899.
Sir Joseph D. Hooker, elected 1907.
Franz Leydig, elected 1900.
M. Jules H. Poincaré, elected 1900.
Eduard Strasburger, elected 1908.
Prof. Ferdinand Zirkel, elected 1904.

and the following Corresponding Members:

Paul Schweitzer, elected 1867.
George Jarvis Brush, elected 1876.

There are at present upon our rolls 44 Honorary Members and 125 Corresponding Members.

Respectfully submitted,

Henry E. Crampton,
Corresponding Secretary.

REPORT OF THE RECORDING SECRETARY.

During the year 1912, the Academy held 8 business meetings and 26 sectional meetings, at which 65 stated papers were presented as follows:

Section of Geology and Mineralogy, 24 papers; Section of Biology, 16 papers; Section of Astronomy, Physics and Chemistry, 6 papers; Section of Anthropology and Psychology, 19 papers.

Seven public lectures have been given at the American Museum to the members of the Academy and the Affiliated Societies and their friends, as follows:

"The Planet Mars." By Edward E. Barnard.
"Astronomy, Education and Culture." By F. S. Archenhold.
"Geology and Mineral Resources of Alaska." By Alfred H. Brooks.
"Sanitation of the Panama Canal." By James F. B. Bowles.
"Results of the Suture of Blood Vessels and the Transplantation of Organs." By Alexis Carrel.
"The Seismograph and What it Teaches." By Harry Fielding Reid.
"Experimental Evolution." By Hugo de Vries.

At the present time, the membership of the Academy is 488, which includes 468 Active Members, 22 of whom are Associate Members, 86

Fellows, 90 Life Members and 11 Patrons and 20 Non-resident Members. There have been 10 deaths during the year, 12 resignations have become effective, 7 names have been dropped from the roll for nonpayment of dues, 2 names have been transferred to the list of Non-Resident Members. Twelve new members have been elected during the year. As the membership of the Academy a year ago was 502, there has been a net loss of 14 during the year 1912. Announcement is made with regret of the loss by death of the following members:

Col. John Jacob Astor, Active Member for 17 years.
George Borup, Active Member for 4 months.
Charles F. Cox, Active Member for 36 years.
Prof. Morris Loeb, Active Member for 20 years.
William Pennington, Active Member for 6 years.
Edward Russ, Active Member for 5 years.
Prof. John B. Smith, Active Member for 5 years.
Isidor Straus, Active Member for 7 years.
James Terry, Life Member for 30 years.
Col. John Weir, Life Member for 6 years.

Respectfully submitted,

EDMUND OTIS HOVEY,
Recording Secretary.

REPORT OF THE LIBRARIAN.

The accessions to the library of the New York Academy of Sciences during the current year have been, by exchange and donation, 313 volumes and 1,670 numbers. Successful efforts have again been made to complete imperfect files of publications and special acknowledgments from the Academy are herewith extended to the Institutul Meteorologic al României for the presentation of nineteen volumes (1892–1911); to the Verein für Erdkunde zu Leipzig for the presentation of five volumes (1865–1871); to the Belfast Natural History and Philosophical Society for the presentation of seven volumes (1872–1881) and to the Société Nationale des Sciences Naturelles et Mathématiques de Cherbourg for the presentation of six volumes (1858–1864). I am also pleased to report that the books of the Academy have been more extensively used than during any of the preceding years.

Respectfully submitted,

RALPH W. TOWER,
Librarian.

REPORT OF THE EDITOR.

The Editor reports that during the past fiscal year there were issued pages 177–263 completing Volume XXI and pages 1–337 of Volume XXII.

Respectfully submitted, EDMUND OTIS HOVEY,
Editor.

REPORT OF THE TREASURER.

RECEIPTS.

DECEMBER 1, 1911—NOVEMBER 30, 1912.

Cash on hand, December 1, 1911		$1,356.58
Life membership fees		200.00
Income from investments:		
Interest on mortgages on New York City real estate	$860.00	
Interest on railroad and other bonds	1,375.00	
		2,235.00
Interest on bank balances		48.29
Active membership dues, 1909	$10.00	
“ “ “ 1910	50.00	
“ “ “ 1911	245.00	
“ “ “ 1912	3,185.00	
		3,490.00
Associate membership dues, 1911	$6.00	
“ “ “ 1912	45.00	
		51.00
Sales of publications		89.30
Subscriptions to annual dinner		178.00
Total		$7,648.17

DISBURSEMENTS.

DECEMBER 1, 1911—NOVEMBER 30, 1912.

Publications on account of Annals	$1,511.01
Publication of *Bulletin*	597.75
Recording Secretary's expenses	293.55
Recording Secretary's and Editor's allowance	1,200.00
Lecture Committee	200.00
General expenses	300.65
Esther Herrman Research Fund (grants)	800.00
Annual meeting and dinner	184.70
Purchase of bond	975.00
Interest charge on bond purchased	5.00
Section of Geology and Mineralogy	25.00
Cash on hand	1,555.51
Total	$7,648.17

Balance Sheet, November 30, 1912.

Investments (cost)	$42,631.25	Permanent Fund	$22,812.57
Cash on hand	1,555.51	Publication Fund	3,000.00
		Audubon Fund	2,500.00
		Esther Herrman Research Fund	10,000.00
		John Strong Newberry Fund	1,000.00
		Income Permanent Fund	2,624.32
		Income Audubon Fund	334.75
		Income Esther Herrman Fund	1,465.96
		Income Newberry Fund	449.16
	$44,186.76		$44,186.76

Henry L. Doherty,
Treasurer.

8 January, 1913.

Examined and found to be correct,

George F. Kunz,
Frederic S. Lee,
Auditing Committee.

THE ORGANIZATION OF THE NEW YORK ACADEMY OF SCIENCES

THE ORIGINAL CHARTER

AN ACT TO INCORPORATE THE LYCEUM OF NATURAL HISTORY IN THE CITY OF NEW YORK

Passed April 20, 1818

Whereas, The members of the Lyceum of Natural History have petitioned for an act of incorporation, and the Legislature, impressed with the importance of the study of Natural History, as connected with the wants, the comforts and the happiness of mankind, and conceiving it their duty to encourage all laudable attempts to promote the progress of science in this State—therefore,

1. *Be it enacted by the People of the State of New York represented in Senate and Assembly,* That Samuel L. Mitchill, Casper W. Eddy, Frederick C. Schaeffer, Nathaniel Paulding, William Cooper, Benjamin P. Kissam, John Torrey, William Cumberland, D'Jurco V. Knevels, James Clements and James Pierce, and such other persons as now are, and may from time to time become members, shall be, and hereby are constituted a body corporate and politic, by the name of Lyceum of Natural History in the City of New York, and that by that name they shall have perpetual succession, and shall be persons capable of suing and being sued, pleaded and being impleaded, answering and being answered unto, defending and being defended, in all courts and places whatsoever; and may have a common seal, with power to alter the same from time to time; and shall be capable of purchasing, taking, holding, and enjoying to them and their successors, any real estate in fee simple or otherwise, and any goods, chattels, and personal estate, and of selling, leasing, or otherwise disposing of said real or personal estate, or any part thereof, at their will and pleasure: *Provided always,* that the clear annual value or income of such real or personal estate shall not exceed the sum of five thousand dollars: *Provided,* however, that the funds of the said Corporation shall be used and appropriated to the promotion of the objects stated in the preamble to this act, and those only.

2. *And be it further enacted,* That the said Society shall from time to time, forever hereafter, have power to make, constitute, ordain, and establish such by-laws and regulations as they shall judge proper, for the elec-

tion of their officers; for prescribing their respective functions, and the mode of discharging the same; for the admission of new members; for the government of the officers and members thereof; for collecting annual contributions from the members towards the funds thereof; for regulating the times and places of meeting of the said Society; for suspending or expelling such members as shall neglect or refuse to comply with the by-laws or regulations, and for the managing or directing the affairs and concerns of the said Society: *Provided* such by-laws and regulations be not repugnant to the Constitution and laws of this State or of the United States.

3. *And be it further enacted,* That the officers of the said Society shall consist of a President and two Vice-Presidents, a Corresponding Secretary, a Recording Secretary, a Treasurer, and five Curators, and such other officers as the Society may judge necessary; who shall be annually chosen, and who shall continue in office for one year, or until others be elected in their stead; that if the annual election shall not be held at any of the days for that purpose appointed, it shall be lawful to make such election at any other day; and that five members of the said Society, assembling at the place and time designated for that purpose by any by-law or regulation of the Society, shall constitute a legal meeting thereof.

4. *And be it further enacted,* That Samuel L. Mitchill shall be the President; Casper W. Eddy the First Vice-President; Frederick C. Schaeffer the Second Vice-President; Nathaniel Paulding, Corresponding Secretary; William Cooper, Recording Secretary; Benjamin P. Kissam, Treasurer, and John Torrey, William Cumberland, D'Jurco V. Knevels, James Clements, and James Pierce, Curators; severally to be the first officers of the said Corporation, who shall hold their respective offices until the twenty-third day of February next, and until others shall be chosen in their places.

5. *And be it further enacted,* That the present Constitution of the said Association shall, after passing of this Act, continue to be the Constitution thereof; and that no alteration shall be made therein, unless by a vote to that effect of three-fourths of the resident members, and upon the request in writing of one-third of such resident members, and submitted at least one month before any vote shall be taken thereupon.

State of New York, Secretary's Office.

I CERTIFY the preceding to be a true copy of an original Act of the Legislature of this State, on file in this Office.

ARCH'D CAMPBELL,
Dep. Sec'y.

ALBANY, *April* 29, 1818.

ORDER OF COURT

ORDER OF THE SUPREME COURT OF THE STATE OF NEW YORK TO CHANGE THE NAME OF

THE LYCEUM OF NATURAL HISTORY IN THE CITY OF NEW YORK

TO

THE NEW YORK ACADEMY OF SCIENCES

Whereas, in pursuance of the vote and proceedings of this Corporation to change the corporate name thereof from "The Lyceum of Natural History in the City of New York" to "The New York Academy of Sciences," which vote and proceedings appear to record, an application has been made in behalf of said Corporation to the Supreme Court of the State of New York to legalize and authorize such change, according to the statute in such case provided, by Chittenden & Hubbard, acting as the attorneys of the Corporation, and the said Supreme Court, on the 5th day of January, 1876, made the following order upon such application in the premises, viz:

At a special term of the Supreme Court of the State of New York, held at the Chambers thereof, in the County Court House, in the City of New York, the 5th day of January, 1876:

Present—Hon. Geo. C. Barrett, *Justice.*

In the matter of the application of the Lyceum of Natural History in the City of New York to authorize it to assume the corporate name of the New York Academy of Sciences.

On reading and filing the petition of the Lyceum of Natural History in the City of New York, duly verified by John S. Newberry, the President and chief officer of said Corporation, to authorize it to assume the corporate name of the New York Academy of Sciences, duly setting forth the grounds of said application, and on reading and filing the affidavit of Geo. W. Quackenbush, showing that notice of such application had been duly published for six weeks in the State paper, to wit, *The Albany Evening Journal,* and the affidavit of David S. Owen, showing that notice of such application has also been duly published in the proper newspaper of the County of New York, in which county said Corporation had its business office, to wit, in *The Daily Register,* by which it appears to my satisfaction that such notice has been so published, and on reading and filing the affidavits of Robert H. Browne and J. S. Newberry, thereunto annexed, by which it appears to my satisfaction that the application is made in pursuance of a resolution of the managers of said Corporation to that end named, and there appearing to me to be no reasonable objection to said Corporation so changing its name as prayed in said petition: Now on motion of Grosvenor S. Hubbard, of Counsel for Petitioner, it is

Ordered, That the Lyceum of Natural History in the City of New York be and is hereby authorized to assume the corporate name of The New York Academy of Sciences.

Indorsed: Filed January 5, 1876,

A copy. WM. WALSH, *Clerk.*

Resolution of THE ACADEMY, *accepting the order of the Court, passed February 21, 1876*

And whereas, The order hath been published as therein required, and all the proceedings necessary to carry out the same have been had, Therefore:

Resolved, That the foregoing order be and the same is hereby accepted and adopted by this Corporation, and that in conformity therewith the corporate name thereof, from and after the adoption of the vote and resolution herein above referred to, be and the same is hereby declared to be THE NEW YORK ACADEMY OF SCIENCES.

AMENDED CHARTER

MARCH 19, 1902

CHAPTER 181 OF THE LAWS OF 1902

AN ACT to amend chapter one hundred and ninety-seven of the laws of eighteen hundred and eighteen, entitled "An act to incorporate the Lyceum of Natural History in the City of New York," a Corporation now known as The New York Academy of Sciences and to extend the powers of said Corporation.

(Became a law March 19, 1902, with the approval of the Governor. Passed, three-fifths being present.)

The People of the State of New York, represented in Senate and Assembly, do enact as follows:

Section I. The Corporation incorporated by chapter one hundred and ninety-seven of the laws of eighteen hundred and eighteen, entitled "An act to incorporate the Lyceum of Natural History in the City of New York," and formerly known by that name, but now known as The New York Academy of Sciences through change of name pursuant to order made by the supreme court at the city and county of New York, on January fifth, eighteen hundred and seventy-six, is hereby authorized and empowered to raise money for, and to erect and maintain, a building in the city of New York for its use, and in which also at its option other scientific societies may be admitted and have their headquarters upon such terms as said Corporation may make with them, portions of which building may be also rented out by said Corporation for any lawful uses for the purposes of obtaining income for the maintenance of such building and for the promotion of the objects of the Corporation; to establish, own, equip, and administer a public library, and a museum having especial reference to scientific subjects; to publish communications, transactions, scientific works, and periodicals; to give scientific instruction by lectures or otherwise; to encourage the advancement of scientific research and discovery, by gifts of money, prizes, or other assistance thereto. The building, or rooms, of said Corporation in the City of New York used exclusively for library or scientific purposes shall be subject to the provisions and be entitled to the benefits of subdivision seven of section four of chapter nine hundred and eight of the laws of eighteen hundred and ninety-six, as amended.

Section II. The said Corporation shall from time to time forever hereafter have power to make, constitute, ordain, and establish such by-laws and regulations as it shall judge proper for the election of its officers; for prescribing their respective functions, and the mode of discharging the same; for the admission of new members; for the government of officers and members thereof; for collecting dues and contributions towards the funds thereof; for regulating the times and places of meeting of said Corporation; for suspending or expelling such members as shall neglect or refuse to comply with the by-laws or regulations, and for managing or directing the affairs or concerns of the said Corporation: and may from time to time alter or modify its constitution, by-laws, rules, and regulations.

SECTION III. The officers of the said Corporation shall consist of a president and two or more vice-presidents, a corresponding secretary, a recording secretary, a treasurer, and such other officers as the Corporation may judge necessary; who shall be chosen in the manner and for the terms prescribed by the constitution of the said Corporation.

SECTION IV. The present constitution of the said Corporation shall, after the passage of this act, continue to be the constitution thereof until amended as herein provided. Such constitution as may be adopted by a vote of not less than three-quarters of such resident members and fellows of the said New York Academy of Sciences as shall be present at a meeting thereof, called by the Recording Secretary for that purpose, within forty days after the passage of this act, by written notice duly mailed, postage prepaid, and addressed to each fellow and resident member at least ten days before such meeting, at his last known place of residence, with street and number when known, which meeting shall be held within three months after the passage of this act, shall be thereafter the constitution of the said New York Academy of Sciences, subject to alteration or amendment in the manner provided by such constitution.

SECTION V. The said Corporation shall have power to consolidate, to unite, to co-operate, or to ally itself with any other society or association in the city of New York organized for the promotion of the knowledge or the study of any science, or of research therein, and for this purpose to receive, hold, and administer real and personal property for the uses of such consolidation, union, co-operation, or alliance subject to such terms and regulations as may be agreed upon with such associations or societies.

SECTION VI. This act shall take effect immediately.

STATE OF NEW YORK,
OFFICE OF THE SECRETARY OF STATE.

I have compared the preceding with the original law on file in this office, and do hereby certify that the same is a correct transcript therefrom, and the whole of said original law.

Given under my hand and the seal of office of the Secretary of State, at the city of Albany, this eighth day of April, in the year one thousand nine hundred and two.

JOHN T. MCDONOUGH,
Secretary of State.

CONSTITUTION

Adopted, April 24, 1902, and Amended at Subsequent Times

Article I. The name of this Corporation shall be The New York Academy of Sciences. Its object shall be the advancement and diffusion of scientific knowledge, and the center of its activities shall be in the City of New York.

Article II. The Academy shall consist of five classes of members, namely: Active Members, Fellows, Associate Members, Corresponding Members and Honorary Members. Active Members shall be the members of the Corporation who live in or near the City of New York, or who, having removed to a distance, desire to retain their connection with the Academy. Fellows shall be chosen from the Active Members in virtue of their scientific attainments. Corresponding and Honorary Members shall be chosen from among persons who have attained distinction in some branch of science. The number of Corresponding Members shall not exceed two hundred, and the number of Honorary Members shall not exceed fifty.

Article III. None but Fellows and Active Members who have paid their dues up to and including the last fiscal year shall be entitled to vote or to hold office in the Academy.

Article IV. The officers of the Academy shall be a President, as many Vice-Presidents as there are sections of the Academy, a Corresponding Secretary, a Recording Secretary, a Treasurer, a Librarian, an Editor, six elected Councilors and one additional Councilor from each allied society or association. The annual election shall be held on the third Monday in December, the officers then chosen to take office at the first meeting in January following.

There shall also be elected at the same time a Finance Committee of three.

Article V. The officers named in Article IV shall constitute a Council, which shall be the executive body of the Academy with general control over its affairs, including the power to fill *ad interim* any vacancies that may occur in the offices. Past Presidents of the Academy shall be *ex-officio* members of the Council.

Article VI. Societies organized for the study of any branch of science may become allied with the New York Academy of Sciences by consent of the Council. Members of allied societies may become Active Members of the Academy by paying the Academy's annual fee, but as members of an allied society they shall be Associate Members with the rights and privileges of other Associate Members, except the receipt of its publications. Each allied society shall have the right to delegate one of its members, who is also an Active Member of the Academy, to the Council of the Academy, and such delegate shall have all the rights and privileges of other Councilors.

Article VII. The President and Vice-Presidents shall not be eligible to more than one re-election until three years after retiring from office; the Secretaries and Treasurer shall be eligible to re-election without limitation. The President, Vice-Presidents and Secretaries shall be Fellows. The terms of office of elected Councilors shall be three years, and these officers shall be so grouped that two, at least one of whom shall be a Fellow, shall be elected and two retired each year. Councilors shall not be eligible to re-election until after the expiration of one year.

Article VIII. The election of officers shall be by ballot, and the candidates having the greatest number of votes shall be declared duly elected.

Article IX. Ten members, the majority of whom shall be Fellows, shall form a quorum at any meeting of the Academy at which business is transacted.

Article X. The Academy shall establish by-laws, and may amend them from time to time as therein provided.

Article XI. This Constitution may be amended by a vote of not less than three-fourths of the fellows and three-fourths of the active members present and voting at a regular business meeting of the Academy, provided that such amendment shall be publicly submitted in writing at the preceding business meeting, and provided also that the Recording Secretary shall send a notice of the proposed amendment at least ten days before the meeting, at which a vote shall be taken, to each Fellow and Active Member entitled to vote.

BY-LAWS

As Adopted, October 6, 1902, and Amended at Subsequent Times

Chapter I

OFFICERS

1. *President.* It shall be the duty of the President to preside at the business and special meetings of the Academy; he shall exercise the customary duties of a presiding officer.

2. *Vice-Presidents.* In the absence of the President, the senior Vice-President, in order of Fellowship, shall act as the presiding officer.

3. *Corresponding Secretary.* The Corresponding Secretary shall keep a corrected list of the Honorary and Corresponding Members, their titles and addresses, and shall conduct all correspondence with them. He shall make a report at the Annual Meeting.

4. *Recording Secretary.* The Recording Secretary shall keep the minutes of the Academy proceedings; he shall have charge of all documents belonging to the Academy, and of its corporate seal, which he shall affix and attest as directed by the Council; he shall keep a corrected list of the Active Members and Fellows, and shall send them announcements of the Meetings of the Academy; he shall notify all Members and Fellows of their election, and committees of their appointment; he shall give notice to the Treasurer and to the Council of matters requiring their action, and shall bring before the Academy business presented by the Council. He shall make a report at the Annual Meeting.

5. *Treasurer.* The Treasurer shall have charge, under the direction of the Council, of all moneys belonging to the Academy, and of their investment. He shall receive all fees, dues and contributions to the Academy, and any income that may accrue from property or investment; he shall report to the Council at its last meeting before the Annual Meeting the names of members in arrears; he shall keep the property of the Academy insured, and shall pay all debts against the Academy the discharge of which shall be ordered by the Council. He shall report to the Council from time to time the state of the finances, and at the Annual Meeting shall report to the Academy the receipts and expenditures for the entire year.

6. *Librarian.* The Librarian shall have charge of the library, under the general direction of the Library Committee of the Council, and shall conduct all correspondence respecting exchanges of the Academy. He shall make a report on the condition of the library at the Annual Meeting.

7. *Editor.* The editor shall have charge of the publications of the Academy, under the general direction of the Publication Committee of the Council. He shall make a report on the condition of the publications at the Annual Meeting.

CHAPTER II

COUNCIL

1. *Meetings.* The Council shall meet once a month, or at the call of the President. It shall have general charge of the affairs of the Academy.

2. *Quorum.* Five members of the Council shall constitute a quorum.

3. *Officers.* The President, Vice-Presidents and Recording Secretary of the Academy shall hold the same offices in the Council.

4. *Committees.* The Standing Committees of the Council shall be: (1) an Executive Committee consisting of the President, Treasurer, and Recording Secretary; (2) a Committee on Publication; (3) a Committee on the Library, and such other committees as from time to time shall be authorized by the Council. The action of these committees shall be subject to revision by the Council.

CHAPTER III

FINANCE COMMITTEE

The Finance Committee of the Academy shall audit the Annual Report of the Treasurer, and shall report on financial questions whenever called upon to do so by the Council.

CHAPTER IV

ELECTIONS

1. *Active Members.* (*a*) Active Members shall be nominated in writing to the Council by at least two Active Members or Fellows. If approved by the Council, they may be elected at the succeeding business meeting.

(*b*) Any Active Member who, having removed to a distance from the city of New York, shall nevertheless express a desire to retain his connection with the Academy, may be placed by vote of the Council on a list of Non-Resident Members. Such members shall relinquish the full privileges and obligations of Active Members. (*Vide* Chapters V and X.)

2. *Associate Members.* Workers in science may be elected to Associate Membership for a period of two years in the manner prescribed for Active Members. They shall not have the power to vote and shall not be eligible to election as Fellows, but may receive the publications. At any time subsequent to their election they may assume the full privileges of Active Members by paying the dues of such Members.

3. *Fellows, Corresponding Members and Honorary Members.* Nominations for Fellows, Corresponding Members and Honorary Members may be made in writing either to the Recording Secretary or to the Council at its meeting prior to the Annual Meeting. If approved by the Council, the nominees shall then be balloted for at the Annual Meeting.

4. *Officers.* Nominations for Officers, with the exception of Vice-Presidents, may be sent in writing to the Recording Secretary, with the name of the proposer, at any time not less than thirty days before the Annual Meeting. Each section of the Academy shall nominate a candi-

date for Vice-President, who, on election, shall be Chairman of the section; the names of such nominees shall be sent to the Recording Secretary properly certified by the sectional secretaries, not less than thirty days before the Annual Meeting. The Council shall then prepare a list which shall be the regular ticket. This list shall be mailed to each Active Member and Fellow at least one week before the Annual Meeting. But any Active Member or Fellow entitled to vote shall be entitled to prepare and vote another ticket.

Chapter V

DUES

1. *Dues.* The annual dues of Active Members and Fellows shall be $10, payable in advance at the time of the Annual Meeting; but new members elected after May 1, shall pay $5 for the remainder of the fiscal year.

The annual dues of elected Associate Members shall be $3, payable in advance at the time of the Annual Meeting.

Non-Resident Members shall be exempt from dues, so long as they shall relinquish the privileges of Active Membership. (*Vide* Chapter X.)

2. *Members in Arrears.* If any Active Member or Fellow whose dues remain unpaid for more than one year, shall neglect or refuse to pay the same within three months after notification by the Treasurer, his name may be erased from the rolls by vote of the Council. Upon payment of his arrears, however, such person may be restored to Active Membership or Fellowship by vote of the Council.

3. *Renewal of Membership.* Any Active Member or Fellow who shall resign because of removal to a distance from the city of New York, or any Non-Resident Member, may be restored by vote of the Council to Active Membership or Fellowship at any time upon application.

Chapter VI

PATRONS, DONORS AND LIFE MEMBERS

1. *Patrons.* Any person contributing at one time $1,000 to the general funds of the Academy shall be a Patron and, on election by the Council, shall enjoy all the privileges of an Active Member.

2. *Donors.* Any person contributing $50 or more annually to the general funds of the Academy shall be termed a Donor and, on election by the Council, shall enjoy all the privileges of an Active Member.

3. *Life Members.* Any Active Member or Fellow contributing at one time $100 to the general funds of the Academy shall be a Life Member

and shall thereafter be exempt from annual dues; and any Active Member or Fellow who has paid annual dues for twenty-five years or more may, upon his written request, be made a life member and be exempt from further payment of dues.

Chapter VII

SECTIONS

1. *Sections.* Sections devoted to special branches of Science may be established or discontinued by the Academy on the recommendation of the Council. The present sections of the Academy are the Section of Astronomy, Physics and Chemistry, the Section of Biology, the Section of Geology and Mineralogy and the Section of Anthropology and Psychology.

2. *Organization.* Each section of the Academy shall have a Chairman and a Secretary, who shall have charge of the meetings of their Section. The regular election of these officers shall take place at the October or November meeting of the section, the officers then chosen to take office at the first meeting in January following.

3. *Affiliation.* Members of scientific societies affiliated with the Academy, and members of the Scientific Alliance, or men of science introduced by members of the Academy, may attend the meetings and present papers under the general regulations of the Academy.

Chapter VIII

MEETINGS

1. *Business Meetings.* Business meetings of the Academy shall be held on the first Monday of each month from October to May inclusive.

2. *Sectional Meetings.* Sectional meetings shall be held on Monday evenings from October to May inclusive, and at such other times as the Council may determine. The sectional meeting shall follow the business meeting when both occur on the same evening.

3. *Annual Meeting.* The Annual Meeting shall be held on the third Monday in December.

4. *Special Meetings.* A special meeting may be called by the Council, provided one week's notice be sent to each Active Member and Fellow, stating the object of such meeting.

CHAPTER IX

ORDER OF BUSINESS

1. *Business Meetings.* The following shall be the order of procedure at business meetings:

   1. Minutes of the previous business meeting.
   2. Report of the Council.
   3. Reports of Committees.
   4. Elections.
   5. Other business.

2. *Sectional Meetings.* The following shall be the order of procedure at sectional meetings:

   1. Minutes of the preceding meeting of the section.
   2. Presentation and discussion of papers.
   3. Other scientific business.

3. *Annual Meetings.* The following shall be the order of procedure at Annual Meetings:

   1. Annual reports of the Corresponding Secretary, Recording Secretary, Treasurer, Librarian, and Editor.
   2. Election of Honorary Members, Corresponding Members, and Fellows.
   3. Election of officers for the ensuing year.
   4. Annual address of the retiring President.

CHAPTER X

PUBLICATIONS

1. *Publications.* The established publications of the Academy shall be the *Annals* and the *Memoirs.* They shall be issued by the Editor under the supervision of the Committee on Publications.

2. *Distribution.* One copy of all publications shall be sent to each Patron, Life Member, Active Member and Fellow; *provided,* that upon inquiry by the Editor such Members or Fellows shall signify their desire to receive them.

3. *Publication Fund.* Contributions may be received for the publication fund, and the income thereof shall be applied toward defraying the expenses of the scientific publications of the Academy.

CHAPTER XI

GENERAL PROVISIONS

1. *Debts.* No debts shall be incurred on behalf of the Academy, unless authorized by the Council.

2. *Bills.* All bills submitted to the Council must be certified as to correctness by the officers incurring them.

3. *Investments.* All the permanent funds of the Academy shall be invested in United States or in New York State securities or in first mortgages on real estate, provided they shall not exceed sixty-five per cent. of the value of the property, or in first-mortgage bonds of corporations which have paid dividends continuously on their common stock for a period of not less than five years. All income from patron's fees, life-membership fees and donor's fees shall be added to the permanent fund.

4. *Expulsion, etc.* Any Member or Fellow may be censured, suspended or expelled, for violation of the Constitution or By-Laws, or for any offence deemed sufficient, by a vote of three-fourths of the Members and three-fourths of the Fellows present at any business meeting, provided such action shall have been recommended by the Council at a previous business meeting, and also, that one month's notice of such recommendation and of the offence charged shall have been given the Member accused.

5. *Changes in By-Laws.* No alteration shall be made in these By-Laws unless it shall have been submitted publicly in writing at a business meeting, shall have been entered on the Minutes with the names of the Members or Fellows proposing it, and shall be adopted by two-thirds of the Members and Fellows present and voting at a subsequent business meeting.

MEMBERSHIP OF THE NEW YORK ACADEMY OF SCIENCES

HONORARY MEMBERS

31 December, 1912.

Elected.	
1912.	Frank D. Adams, Montreal, Canada.
1898.	Arthur Auwers, Berlin, Germany.
1889.	Charles Barrois, Lille, France.
1907.	William Bateson, Cambridge, England.
1910.	Theodor Boveri, Würzburg, Germany.
1901.	Charles Vernon Boys, London, England.
1904.	W. C. Brögger, Christiana, Norway.
1911.	Hermann Credner, Leipzig, Germany.
1876.	W. Boyd Dawkins, Manchester, England.
1902.	Sir James Dewar, Cambridge, England.
1901.	Emil Fischer, Berlin, Germany.
1876.	Sir Archibald Geikie, Haslemere, Surrey, England.
1901.	James Geikie, Edinburgh, Scotland.
1898.	Sir David Gill, London, England.
1909.	K. F. Göbel, Munich, Germany.
1889.	George Lincoln Goodale, Cambridge, Mass.
1909.	Paul von Groth, Munich, Germany.
1894.	Ernst Häckel, Jena, Germany.
1912.	George E. Hale, Mt. Wilson, Calif.
1899.	Julius Hann, Vienna, Austria.
1898.	George W. Hill, West Nyack, N. Y.
1896.	Ambrosius A. W. Hubrecht, Utrecht, Netherlands.
1896.	Felix Klein, Göttingen, Germany.
1909.	Alfred Lacroix, Paris, France.
1876.	Viktor von Lang, Vienna, Austria.
1898.	E. Ray Lankester, London, England.
1880.	Sir Norman Lockyer, London, England.
1911.	Ernst Mach, Vienna, Austria.
1912.	Iliya Metchnikof, Paris, France,
1912.	Sir John Murray, Edinburgh, Scotland.
1898.	Fridtjof Nansen, Christiana, Norway.
1908.	Wilhelm Ostwald, Gross-Bothen, Germany.
1898.	Albrecht Penck, Berlin, Germany.

Elected.	
1898.	Wilhelm Pfeffer, Leipzig, Germany.
1900.	Edward Charles Pickering, Cambridge, Mass.
1911.	Edward Bagnall Poulton, Oxford, England.
1901.	Sir William Ramsay, London, England.
1899.	Lord Rayleigh, Witham, Essex, England.
1898.	Hans H. Reusch, Christiania, Norway.
1887.	Sir Henry Enfield Roscoe, London, England.
1887.	Heinrich Rosenbusch, Heidelberg, Germany.
1912.	Sho Watasé, Tokyo, Japan.
1904.	Karl von den Steinen, Berlin, Germany.
1896.	Joseph John Thomson, Cambridge, England.
1900.	Edward Burnett Tylor, Oxford, England.
1904.	Hugo de Vries, Amsterdam, Netherlands.
1907.	James Ward, Cambridge, England.
1909.	August Weissmann, Freiburg, Germany.
1904.	Wilhelm Wundt, Leipzig, Germany.

CORRESPONDING MEMBERS

31 December, 1912.

1883.	Charles Conrad Abbott, Trenton, N. J.
1891.	José G. Aguilera, Mexico City, Mexico.
1890.	William De Witt Alexander, Honolulu, Hawaii.
1899.	C. W. Andrews, London, England.
1876.	John Howard Appleton, Providence, R. I.
1899.	J. G. Baker, Kew, England.
1898.	Isaac Bagley Balfour, Edinburgh, Scotland.
1878.	Alexander Graham Bell, Washington, D. C.
1867.	Edward L. Berthoud, Golden, Colo.
1897.	Herbert Bolton, Bristol, England.
1899.	G. A. Boulenger, London, England.
1874.	T. S. Brandegee, Berkeley, Calif.
1884.	John C. Branner, Stanford University, Calif.
1894.	Bohuslay Brauner, Prague, Bohemia.
1874.	William Brewster, Cambridge, Mass.
1898.	T. C. Chamberlin, Chicago, Ill.
1876.	Frank Wigglesworth Clarke, Washington, D. C.
1891.	L. Clerc, Ekaterinburg, Russia.
1877.	Theodore B. Comstock, Los Angeles, Calif.

Elected.

1868. M. C. Cooke, London, England.
1876. H. B. Cornwall, Princeton, N. J.
1880. Charles B. Cory, Boston, Mass.
1877. Joseph Crawford, Philadelphia, Pa.
1895. Henry P. Cushing, Cleveland, O.
1879. T. Nelson Dale, Pittsfield, Mass.
1870. William Healey Dall, Washington, D. C.
1885. Edward Salisbury Dana, New Haven, Conn.
1898. William M. Davis, Cambridge, Mass.
1894. Ruthven Deane, Chicago, Ill.
1899. Charles Déperet, Lyons, France.
1890. Orville A. Derby, Rio de Janeiro, Brazil.
1899. Louis Dollo, Brussels, Belgium.
1876. Henry W. Elliott, Lakewood, O.
1880. John B. Elliott, Tulane Univ., La.
1869. Francis E. Engelhardt, Syracuse, N. Y.
1879. Herman Le Roy Fairchild, Rochester, N. Y.
1879. Friedrich Bernhard Fittica, Marburg, Germany.
1885. Lazarus Fletcher, London, England.
1899. Eberhard Fraas, Stuttgart, Germany.
1879. Reinhold Fritzgartner, Tegucigalpa, Honduras.
1870. Grove K. Gilbert, Washington, D. C.
1858. Theodore Nicholas Gill, Washington, D. C.
1865. Charles A. Goessman, Amherst, Mass.
1888. Frank Austin Gooch, New Haven, Conn.
1868. C. R. Greenleaf, San Francisco, Calif.
1883. Marquis Antonio de Gregorio, Palermo, Sicily.
1869. R. J. Lechmere Guppy, Trinidad, British West Indies.
1898. George E. Hale, Mt. Wilson, Calif.
1882. Baron Ernst von Hesse-Wartegg, Lucerne, Switzerland.
1867. C. H. Hitchcock, Honolulu, H. I.
1900. William Henry Holmes, Washington, D. C.
1890. H. D. Hoskold, Buenos Ayres, Argentine Republic.
1896. J. P. Iddings, Brinklow, Md.
1875. Malvern W. Iles, Dubuque, Ia.
1899. Otto Jäkel, Greifswald, Germany.
1876. David Starr Jordan, Stanford University, Calif.
1876. George A. Koenig, Houghton, Mich.
1888. Baron R. Kuki, Tokyo, Japan.
1876. John W. Langley, Cleveland, O.

Elected.	
1876.	S. A. Lattimore, Rochester, N. Y.
1894.	William Libbey, Princeton, N. J.
1899.	Archibald Liversidge, London, England.
1876.	George Macloskie, Princeton, N. J.
1876.	John William Mallet, Charlottesville, Va.
1891.	Charles Riborg Mann, Chicago, Ill.
1867.	George F. Matthew, St. John, N. B., Canada.
1874.	Charles Johnson Maynard, West Newton, Mass.
1874.	Theodore Luqueer Mead, Oviedo, Fla.
1888.	Seth E. Meek, Chicago, Ill.
1892.	J. de Mendizábal-Tamborrel, Mexico City, Mexico.
1874.	Clinton Hart Merriam, Washington, D. C.
1898.	Mansfield Merriam, South Bethlehem, Pa.
1878.	Charles Sedgwick Minot, Boston, Mass.
1876.	William Gilbert Mixter, New Haven, Conn.
1890.	Richard Moldenke, Watchung, N. J.
1895.	C. Lloyd Morgan, Bristol, England.
1864.	Edward S. Morse, Salem, Mass.
1898.	George Murray, London, England.
——.	Eugen Netto, Giessen, Germany.
1866.	Alfred Newton, Cambridge, England.
1897.	Francis C. Nicholas, New York, N. Y.
1882.	Henry Alfred Alford Nicholls, Dominica, B. W. I.
1880.	Edward J. Nolan, Philadelphia, Pa.
1879.	Frederick A. Ober, Hackensack, N. J.
1876.	John M. Ordway, New Orleans, La.
1900.	George Howard Parker, Cambridge, Mass.
1876.	Stephen F. Peckham, New York, N. Y.
1877.	Frederick Prime, Philadelphia, Pa.
1868.	Raphael Pumpelly, Newport, R. I.
1876.	B. Alex. Randall, Philadelphia, Pa.
1876.	Ira Remsen, Baltimore, Md.
1874.	Robert Ridgway, Washington, D. C.
1886.	William L. Robb, Troy, N. Y.
1876.	Samuel P. Sadtler, Philadelphia, Pa.
1899.	D. Max Schlosser, Munich, Germany.
1898.	W. B. Scott, Princeton, N. J.
1894.	W. T. Sedgwick, Boston, Mass.
1876.	Andrew Sherwood, Portland, Ore.
1883.	J. Ward Smith, Newark, N. J.

Elected.	
1895.	Charles H. Smyth, Jr., Princeton, N. J.
1890.	J. Selden Spencer, Tarrytown, N. Y.
1896.	Robert Stearns, Los Angeles, Calif.
1890.	Walter Le Conte Stevens, Lexington, Va.
1876.	Francis H. Storer, Boston, Mass.
1885.	Rajah Sourindro Mohun Tagore, Calcutta, India.
1893.	J. P. Thomson, Brisbane, Queensland, Australia.
1899.	R. H. Traquair, Colinton, Scotland.
1877.	John Trowbridge, Cambridge, Mass.
1876.	D. K. Tuttle, Philadelphia, Pa.
1871.	Henri Van Heurck, Antwerp, Belgium.
1900.	Charles R. Van Hise, Madison, Wis.
1867.	Addison Emery Verrill, New Haven, Conn.
1890.	Anthony Wayne Vogdes, San Diego, Calif.
1898.	Charles Doolittle Walcott, Washington, D. C.
1876.	Leonard Waldo, New York, N. Y.
1897.	Stuart Weller, Chicago, Ill.
1874.	I. C. White, Morgantown, W. Va.
1898.	Henry Shaler Williams, Ithaca, N. Y.
1898.	N. H. Winchell, Minneapolis, Minn.
1866.	Horatio C. Wood, Philadelphia, Pa.
1899.	A. Smith Woodward, London, England.
1876.	Arthur Williams Wright, New Haven, Conn.
1876.	Harry Crècy Yarrow, Washington, D. C.

ACTIVE MEMBERS

1912

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Abercrombie, David T.
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*Allen, J. A., Ph.D.
Allen, James Lane
*†Allis, Edward Phelps, Jr., Ph.D.
Ames, Oakes
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Anderson, A. J. C.
*†Andrews, Roy C.
†Anthony, R. A.
Arctowski, Dr. Henryk
Arend, Francis J.
†Armstrong, S. T., M.D.
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Astor, John Jacob[1]
Avery, Samuel P.
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*Barnhart, John Hendley
Barron, George D.
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*Beebe, C. William
Beller, A.
†Bergstresser, Charles M.
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van Beuren, F. T.
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Bishop, Miss Mary C.
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†Blumenthal, George
*Boas, Prof. Franz
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Böhler, Richard F.
Borup, George[1]
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Boyd, James
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*Bristol, Prof. Charles L.
Bristol, Jno. I. D.
*§Britton, Prof. N. L., Ph.D.
*§Brown, Hon. Addison
Brown, Edwin H.
Browne, T. Quincy
*Brownell, Silas B., LL.D.
Bulkley, L. Duncan
Burr, Winthrop
*Bush, Wendell T.
Byrne, Joseph, M.D.
*Byrnes, Miss Esther F., Ph.D.
Camp, Frederick A.

---

[1] Deceased.

*Campbell, Prof. William, Ph.D.
*Campbell, Prof. William M.
Canfield, R. A.
Cannon, J. G.
Carlebach, Walter Maxwell
*§Casey, Col. T. L., U. S. A.
Cassard, William J.
Cassebeer, H. A., Jr.
*†Cattell, Prof. J. McKeen, Ph.D.
*†Chandler, Prof. C. F., Ph.D.
§Chapin, Chester W.
*Chapman, Frank M.
†Chaves, José E.
*Cheesman, Timothy M., M.D.
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Chubb, Percy
Clarkson, Banyer
Cline, M. Hunt
†Clyde, Wm. P.
Cohn, Julius M.
Collier, Robert J.
†Collord, George W.
Combe, Mrs. William
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de Coppet, E. J.
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Crosby, Maunsell S.
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Curtis, G. Warrington
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Davis, Dr. Charles H.
Davis, David T.
*†Davis, William T.
*†Dean, Prof. Bashford, Ph.D.
†Delafield, Maturin L., Jr.
Delano, Warren, Jr.
Demorest, William C.
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De Vinne, Theodore L.
De Witt, William G.
Dickerson, Edward N.
Diefenthäler, C. E.
Dimock, George E.
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†Dodge, Miss Grace H.
*Dodge, Prof. Richard E., A.M.
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*†Douglas, James
Douglass, Alfred
Draper, Mrs. M. A. P.
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*Dudley, P. H., Ph.D.
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†Dunn, Gano
†Dunscombe, George Elsworth
*Dutcher, Wm.
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Dwight, Mrs. M. E.
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*Eastman, Prof. Charles R.
*†Elliott, Prof. A. H., Ph.D.
Emmet, C. Temple
Eno, William Phelps
Estabrook, A. F.
Evarts, Allen W.
*Eyerman, John
Fairchild, Charles S.
Fargo, James C.
Farmer, Alexander S.
*Farrand, Prof. Livingston, M.D.
Farrington, Wm. H.
Fearing, D. B.
Ferguson, Mrs. Juliana Armour
§Field, C. de Peyster
Field, William B. Osgood
*Finley, Pres. John H.
*Fishberg, Maurice, M.D.

Follett, Richard E.
Foot, James D.
†Ford, James B.
Fordyce, John A.
de Forest, Robert W.
Friedrick, J. J.
Frissell, A. S.
Fuller, Charles D.
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Gallatin, F.
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Gibson, R. W.
*Gies, Prof. William J.
*Girty, George H., Ph.D.
Godkin, Lawrence
Goodridge, Frederick G.
Goodwin, Albert C.[1]
§Gould, Edwin
§Gould, George J.
*†Grabau, Prof. Amadeus W.
*Gratacap, Louis P.
Green, James W.
Greenhut, Benedict J.
*Gregory, W. K., Ph.D.
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Guernsey, H. W.
Guggenheim, William
Guinzburg, A. M.
von Hagen, Hugo
Haines, John P.
Halls, William, Jr.
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Hardon, Mrs. H. W.
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†Harriman, Mrs. E. H.
Hasslacher, Jacob
Haupt, Louis, M.D.
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Havemeyer, William F.
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*Hering, Prof. Daniel W.
Hewlett, Walter J.
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*Hitchcock, Miss F. R. M., Ph.D.
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Hollenback, Miss Amelia B.
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†Hopkins, George B.
*Hornaday, William T., Sc.D.
Hotchkiss, Henry D.
*†Hovey, Edmund Otis, Ph.D.
*Howe, Marshall A., Ph.D.
†Hoyt, A. W.
†Hoyt, Theodore R.
†Hubbard, Thomas H.
Hubbard, Walter C.
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Humphreys, Frederic H.
†Huntington, Archer M.
*Hussakof, Louis, Ph.D.
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†Hutter, Karl
†Hyde, B. Talbot B.
Hyde, E. Francis
†Hyde, Frederic E., M.D.
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*Hyde, Jesse E.
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*Irving, Prof. John D.
von Isakovics, Alois
Iselin, Mrs. William E.
†Jackson, V. H.
*Jacobi, Abram, M.D.
James, F. Wilton
†Jarvie, James N.
Jennings, Robert E.
*Johnson, Prof. D. W., Ph.D.

---

[1] Deceased.

†Johnston, J. Herbert
Jones, Dwight A.
*§Julien, Alexis A., Ph.D.
Kahn, Otto H.
Kautz-Eulenburg, Miss P. R.
*†Kemp, Prof. James F., Sc.D.
†Keppler, Rudolph
†Kessler, George A.
Kinney, Morris
Kohlman, Charles
*†Kunz, George F., M.A., Ph.D.
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Landon, Francis G.
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Langdon, Woodbury G.
Langeloth, J.
*Langmann, Gustav, M.D.
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Lawrence, John B.
†Lawton, James M.
*Ledoux, Albert R., Ph.D.
*Lee, Prof. Frederic S., Ph.D.
*§Levison, Wallace Goold
Levy, Emanuel
Lichtenstein, M.
Lichtenstein, Paul
Lieb, J. W., Jr.
Lindbo, J. A.
†Loeb, James
*Loeb, Prof. Morris, Ph.D.[1]
†Low, Hon. Seth, LL.D.
*Lowie, Robert H., Ph.D.
*Lucas, F. A., D. Sc.
*Lusk, Prof. Graham, M.D.
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Lyman, Frank
Lyon, Ralph
McCarthy, J. M.
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Mager, F. Robert
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Marcou, John B.[1]
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†Marshall, Louis
Marston, E. S.
†Martin, Bradley
*†Martin, Prof. Daniel S.
*Martin, T. Commerford
*†Matthew, W. D., Ph.D.
Maxwell, Francis T.
§Mead, Walter H.
Mellen, C. S.
*Meltzer, S. J., M.D.
*Merrill, Frederick J. H., Ph.D.
Metz, Herman A.
Milburn, J. G.
Miller, George N., M.D.
*†Miner, Roy Waldo
Mitchell, Arthur M.
Monae-Lesser, A., M.D.
Morgan, J. Pierpont
*Morgan, Prof. Thomas H.
Morgan, William Fellowes
Morris, Lewis R., M.D.
Munn, John P.
†Nash, Nathaniel C.
†Nesbit, Abram G.
Notman, George
Oakes, Francis J.
Ochs, Adolph S.
Oettinger, P. J., M.D.
*†Ogilvie, Miss Ida H., Ph.D.
†Olcott, E. E.
Olmsted, Mrs. Charles T.

---

[1] Deceased.

Oppenheimer, Henry S.
*†Osborn, Prof. H. F., Sc.D., LL.D.
Osborn, William C.
†Osborn, Mrs. William C.
*Osburn, Raymond C., Ph.D.
†Owen, Miss Juliette A.
*Pacini, A. B., Ph.D.
Paddock, Eugene H.[1]
†Parish, Henry
Parsons, C. W.
*Parsons, John E.
†Patten, John
Paul, John J.
*Pedersen, Prof. F. M., Ph.D.
*†Pellew, Prof. C. E., Ph.D.
Pennington, William [1]
†Perkins, William H.
Perry, Charles J.
*Peterson, Frederick, M.D.
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Pfizer, Charles, Jr.
Philipp, P. Bernard
Phoenix, Lloyd
Pierce, Henry Clay
Plant, Albert
Planten, John R.[1]
Polk, Dr. W. M.
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*Poor, Prof. Charles L.
Porter, Eugene H.
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*Post, C. A.
*Post, George B.
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†Roebling, John A.
Rogers, E. L.
Rosenbaum, Selig
Rossbach, Jacob
†de Rubio, H. A. C.
*†Rusby, Prof. Henry H., M.D.
Russ, Edward [1]
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Sage, Dean
Sage, John H.
†Schermerhorn, F. A.
Schiff, Jacob H.
Scholle, A. H.
Schöney, Dr. L.
†Schott, Charles M., Jr.
Scott, George S.[1]
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§Shepard, Mrs. Finley J.
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Shultz, Charles S.
*Sickels, Ivin, M.D.
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Sloan, Benson B.
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*Smith, Ernest E., M.D., Ph.D.
Smith, Frank Morse
Snow, Elbridge G.
*Southwick, Edmund B., Ph.D.
Squibb, Edward H., M.D.
Starr, Louis Morris
*Starr, Prof. M. Allen
*†Stefánsson, V.
Steinbrugge, Edward, Jr.

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[1] Deceased.

†Stetson, F. L.
*Stevens, George T., M.D.
*†Stevenson, Prof. John J., LL.D.
Stokes, James
Stokes, J. G. Phelps
†Stone, Miss Ellen J.
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Strauss, Frederick
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Taylor, William H.
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Thaw, Benjamin
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†Thompson, Robert M.
*Thompson, Prof. W. Gilman
Thompson, Walter
*Thorndike, Prof. Edward L.
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*Townsend, Charles H., Sc.D.
Tows, C. D.
*Trowbridge, Prof. C. C.
Tuckerman, Alfred, Ph.D.
Tuttle, Mrs. B. B.
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†Vail, Theo. N.
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†Van Slyck, George W.
†Van Wyck, Robert A.
Vreeland, Frederick K.
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*†Waller, Prof. Elwyn, Ph.D.
Warburg, F. N.
Warburg, Paul M.
Ward, Artemas
†Ward, Charles Willis
Ward, John Gilbert
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Watson, John J., Jr.
†Weir, Col. John [1]
*Wells, F. Lyman
Williams, R. H.
Wills, Charles T.
*Wilson, Prof. E. B., Ph.D., LL.D.
Wilson, J. H.
Wilson, Miss M. B., M.D.
*Winslow, Prof. Charles-E. A.
*Wissler, Clark, Ph.D.
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Wood, Mrs. Cynthia A.
Wood, William C.
*Woodbridge, Prof. F. J. E.
*Woodhull, Prof. John F., Ph.D.
*Woodman, Prof. J. Edmund
*Woodward, Prof. R. S.
*Woodworth, Prof. R. S.
Younglove, John, M.D.
Zabriskie, George

---

[1] Deceased.

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Brown, Harold Chapman, Ph.D.
Brown, T. C.
Byrne, Joseph P.
Fenner, Clarence N., Ph.D.
Fettke, Chas. R.
Gordon, Clarence E.
Hahn, F. F., Ph.D.
Haseman, J. D.
Hunter, George W.
Johnson, Julius M.
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Kirk, Charles T.
McGregor, James Howard
Montague, W. P., Ph.D.
Mook, Charles
Moon, Miss Evangeline
Northup, Dwight
O'Connell, Miss Marjorie
Rogers, G. Sherburne
Stevenson, A. E.
Wood, Miss Elvira

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*Bumpus, H. C.
Burnett, Douglass
*Davis, William H.
English, George L.
Finlay, Prof. G. I.
Frankland, Frederick W.
Hoffman, S. V.
Kendig, Amos B.
*Lloyd, Prof. F. E.
*Mayer, Dr. A. G.
Meyer, Adolph
Petrunkevitch, Alexander, Ph.D.
*Pratt, Dr. J. H.
*Ries, Prof. H.
Reuter, L. H.
*Sumner, Dr. F. B.
*van Ingen, Prof. G.
*Wheeler, Wm. Morton

GENERAL INDEX TO VOLUME XXII

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Titles of Papers in Small Caps

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