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Article XXI.—HYPOTHETICAL OUTLINES OF THE CONTINENTS IN TERTIARY TIMES.

By W. D. MATTHEW.

I. INTRODUCTORY.

This series of maps was drawn up about three years ago for the fossil mammal hall in the American Museum of Natural History. We found that it was very necessary to have them, in order to illustrate the geographical distribution of different groups of mammals in past geological epochs. The attempt to plot this distribution on modern maps proved unsatisfactory, as it did not explain the cause of the changes in their range. The various palæographic maps already published were not entirely suited to our purpose and it seemed necessary to draw up a new series to represent the seven principal stages in Cenozoic time. This series of world maps on Mercator's projection[1] shows the supposed continental outlines in each epoch as far back as the opening of the Tertiary period. Beyond that it was not necessary to go for our purpose. The series illustrates the outlines during the Recent, early Pleistocene, mid-Pliocene, mid-Miocene, mid-Oligocene and mid-Eocene epochs, approximately speaking, and at the beginning of the Tertiary period.

It is to be understood that these maps are almost entirely hypothetical. There are very few parts of the earth's surface where the data are really adequate, and for the greater part there are absolutely no stratigraphic data of any value.

The maps were exhibited before the New York Academy of Sciences in 1903, and were then set aside in order to present more fully the data on which they are based. Opportunity to do this in adequate form has hitherto been lacking, but there have been so many requests for copies of the series that it seemed advisable to publish them even with a brief and imperfect statement of their basis.

It is hardly necessary to say that a subject of this kind is chiefly a matter of compilation. The outlines in different regions are based upon recently expressed views of the most reliable authorities, so far as I have succeeded in finding and comprehending them. In general it represents a somewhat conservative view, retaining as much as possible the present continental outlines except where the evidence for changing them seemed thoroughly adequate.

[1] The maps differ from the ordinary projection in that they are carried to the 75th parallel of north and south latitude instead of to 80° N. and 70° S., as is usual.

The data for these maps are of three kinds:

1. *Geological*, being the direct evidence furnished by the extent of marine formations over what is now land, and various indirect stratigraphical and physical considerations.

2. *Palæontological*, being the direct inferences from the former distribution of faunas.

3. *Zoölogical*, being the indirect inferences from the present distribution of faunas.

These are directly in order of their weight, and inversely in order of their completeness.

As this series was drawn up for use in vertebrate palæontology, it represents in the main conclusions in accord with the evidence from fossil vertebrates, in particular from the mammalia. This evidence, so far as it goes, I regard as of generally greater weight than that based upon the past distribution of other groups, since:

(1) The distribution of large terrestrial mammals appears to be more certainly limited by broad oceanic separation than in the lower groups. For while there is a possibility, slight though it be, of the transfer of small animals and plants across extensive and deep oceans by currents, winds or otherwise, and of their obtaining a permanent foothold, and this almost infinitesimal possibility, multiplied by the almost infinite length of geologic periods, becomes a finite quantity which must be reckoned with, yet in the case of large mammals it becomes apparently a strict physical impossibility for this to occur.

(2) The complicated anatomical structure and high degree of differentiation in the mammalia gives more abundant data for comparison and contrast of the structure, and more adequate and certain evidence as to the degree of relationship between different types, than can be obtained in any other group. We are thus more completely assured against the possibility that their classification and arrangement is an arbitrary and not a natural grouping, a defect which if true even to a slight degree, might completely vitiate the conclusions as to palæogeography based upon present or past distribution of animals.

(3) The comparatively rapid rate of the evolution and divergence of mammalian races limits the time within which migrations or changes in distribution may have occurred, and thus not only fixes more definitely the epoch of former continental connections which might have brought about these changes, but reduces the possibility of accidental transference by other means by reducing the time within which it might have occurred.

The evidence from present distribution of life is of course vastly

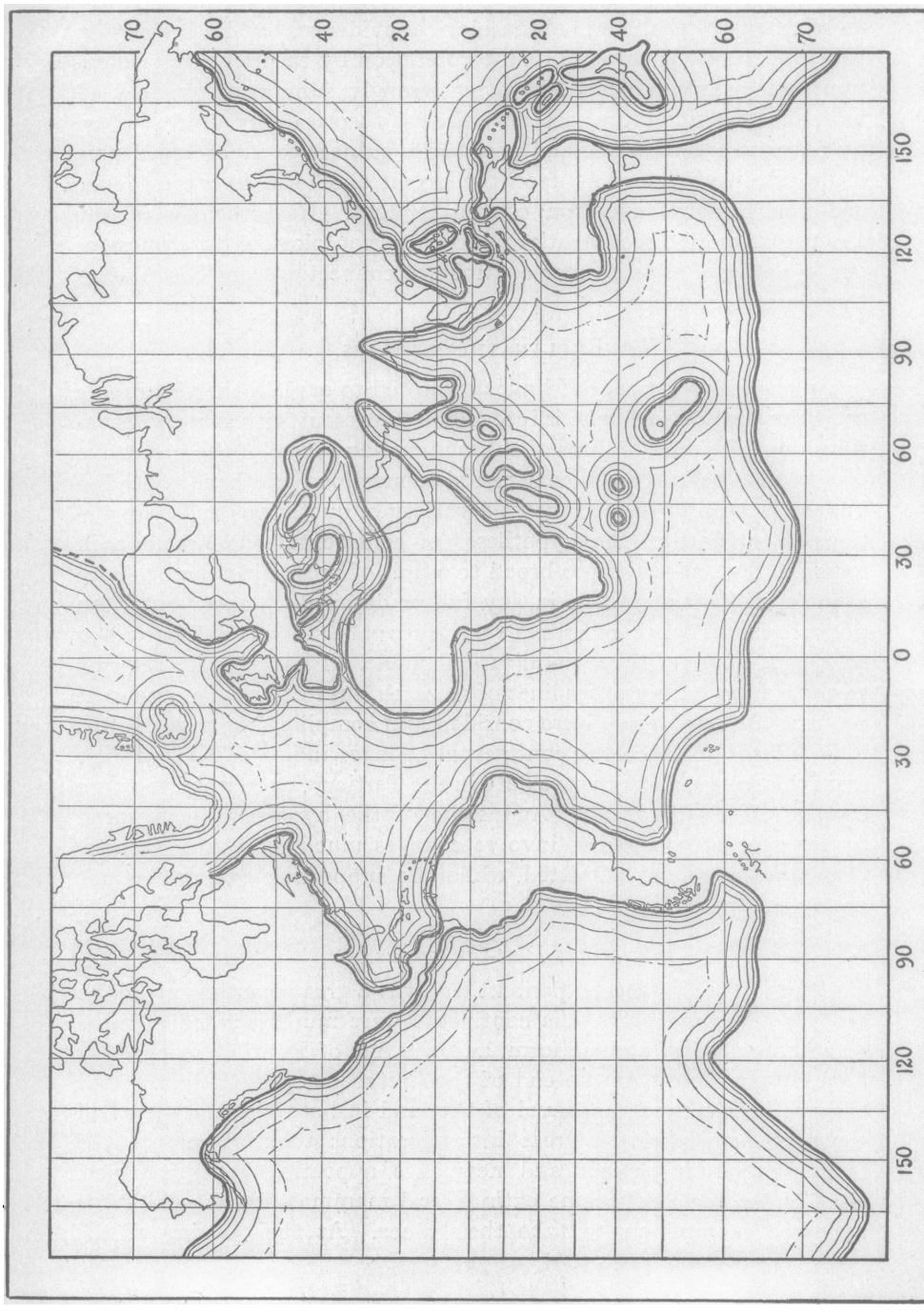
more extensive than the palæontological evidence, but its bearing on palæogeography is through its interpretation by theories of classification and evolution which, however strongly supported by detailed morphological structure, are nevertheless theories only until verified by palæontological facts, and necessarily subject to a varying degree of uncertainty dependent upon the extent and force of the evidence, and the personal equation of the student. Nevertheless, in the absence of more direct stratigraphic or palæontological data, most of our hypotheses as to former continental connections are based upon this class of evidence.

II. Explanation of Maps.

In the following pages I have attempted to explain the geographic conditions which each map is intended to represent, with some observations upon the relationships of the mammalian faunæ of the successive epochs in its bearing upon continental connections, and have appended under the head of regional notes a variety of quotations and observations in support of the hypotheses of continental changes in each region. The subject is too broad to admit of presenting the evidence even from fossil mammals in any full or detailed manner, and I am not sure that all my confreres in vertebrate palæontology will be willing to indorse some of the generalizations made. I have hardly referred to the evidence from other lines of research, especially in invertebrate zoölogy, although these were considered in compiling the maps. But it is difficult to place the continental changes indicated by evidence from this source at any exact date in the Tertiary, even when they are certainly Tertiary at all. And some of the hypotheses advocated by invertebrate zoölogists involve changes much more fundamental than anything here admitted, while the supporting evidence is not nearly so strong.

1. *Post-Cretaceous.*

During the Cretaceous period there was a great overflowing of the sea over the land areas, the continents were much isolated, climate presumably warm and uniform, and the Age of Reptiles reached its final culmination. At the end of the Cretaceous period there seems to have been a great upheaval of the land in both the northern and southern hemispheres. Great intermigrations took place, the old faunas becoming extinct and new ones appearing in their place. Most of the reptiles became extinct, and mammals for the first time appeared in numbers to take their place. At the opening of the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Tertiary we find the mammalian faunæ of Europe and North America quite nearly related as far as can be judged from the fragmentary remains preserved (see Osborn, Correlation between Tertiary Mammal Horizons of Europe and America, Ann. N. Y. Acad. Sci., XIII, 1900, pp. 1–72.) The Notostylops fauna of Patagonia also contains a number of types more or less closely related to the European and especially to the North American fauna of the Basal Eocene, along with a much larger number of animals more remote from any northern groups. We account for this resemblance by supposing that the three continents were united at the close of the Cretaceous.

At this period also I have placed the union of South America and Australia by way of the Antarctic continent, by which the Marsupials reached both continents, as did also many of the lower animals and plants which are common to these two continents, but not found in the rest of the world. This hypothesis has been advocated by a number of authorities of whom Professor Osborn and Dr. Ortmann are the most recent in date, and I have followed their views most nearly. I have omitted the doubtful connection with Africa which has also been proposed to account for a limited number of peculiar southern forms in that continent, as the evidence for it is not nearly as strong, and the difficulties are much greater (as Osborn has pointed out). If the connection occurred at all it may be supposed to have been at an earlier period.

Evidence from Fossil Vertebrates.

Arctocyonidæ.—This group represents a very early specialized branch of the Adaptive Creodonta (the group ancestral to the true Carnivora of the later Tertiary) which paralleled the modern bears in several respects. The European and American genera are very close, so as scarcely to deserve generic separation. They indicate therefore a common source at a not remote epoch. The group was undergoing rapid specialization as shown by the three stages of its evolution occurring in the Puerco Torrejon and Wasatch formations in America; the likeness cannot therefore be attributed to persistence of primitive characters.

Multituberculata.—Two highly specialized genera occur in North America, *Polymastodon* and *Ptilodus* (including *Neoplagiaulax*). The latter is also found in Europe. In the Notostylops beds are found a number of Multituberculates, mostly less specialized and in much greater variety. The inference is that South America was the home of this group, and that certain of its more advanced types made their

way to North America—with difficulty, since there are but two known genera in this country, and these not in the known Patagonian fauna —and thence one of them extended its range to Europe.

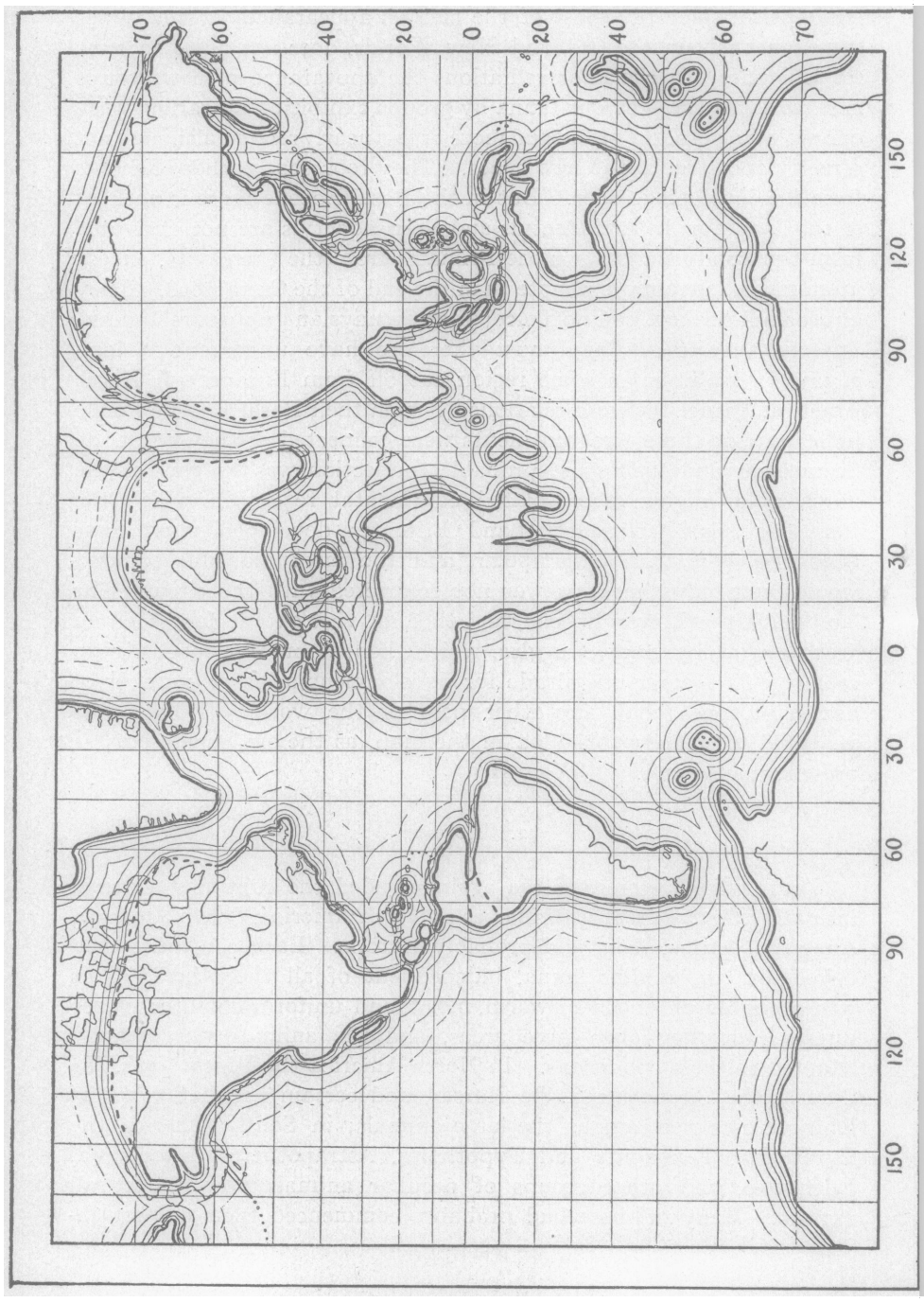
Condylarthra.—While there do not appear to be any genera common to the Notostylops and Torrejon or Puerco faunæ, yet several of the South American genera appear to be nearly related, as for instance *Didolodus* to *Ectoconus*, *Notoprotogonia* to *Euprotogonia*, and quite a number of South American genera can be provisionally referred to the Condylarthra, on the ground of their primitive bunodont, tritubercular or imperfectly quadritubercular teeth. Whenever any advance in the direction of crests or crescents appears in the Notostylops fauna, it seems to be invariably after the Notungulate pattern, as exemplified in the posterior cross-crest which connects with the posterior border of the metacone instead of its anterior border, the metaconule usually forming a separate cusp or crescent enclosed between the protoloph and metaloph. Generally the ectoloph is prominent without median rib.

The most serious objection to the scheme of continental connections at the end of the Cretaceous lies in the absence from the known faunæ of the Basal Eocene of the ancestors of the greater part of the later Eocene faunæ. In the Lower Eocene of the northern hemisphere appear for the first time Perissodactyls, Artiodactyls, and Primates, already highly specialized as regards their ordinal characters although only in the initial stages of their family differentiation. These cannot be traced back to the Condylarths, Amblypods, Creodonts, and Edentates of the Basal Eocene; their ordinal characters are too sharply defined and too constant to admit of any near connection. The astragalus, for instance, of a Perissodactyl, Artiodactyl, or Primate is as characteristic and easily distinguished in the Wasatch as in any later formation, and no approximation to it is known among Basal Eocene fossils. We must assume that the ancestors of these orders are not represented in the known Basal Eocene faunæ, and considering their abundance in the succeeding fauna the inference is very strong that they were immigrant groups, coming from some unknown region. But where was this region, and how was it prevented from distributing its fauna to other continents before the Lower Eocene? Presumably it was a northern region, presumably also it was an extensive continent, for the animals which it sent forth were of higher development than the European and North American autocthones which they gradually displaced during the Eocene. The theory of a north polar center of radiation, which

explains satisfactorily most of the sudden appearances of new types simultaneously in the Old and New Worlds, does not quite account for this one. In the later radiations the appearance of new groups is heralded in the previous fauna by groups exhibiting an earlier stage of development of the order, and more or less nearly related although not directly ancestral to the new types. They represent earlier offshoots from the developing order. But in the Basal Eocene there is nothing of this kind, for the Artiodactyls and Perissodactyls are not derivable from the Condylarthra, nor the Primates from the Creodonts, except at an epoch much more remote than the end of the Cretaceous. They appear full-fledged, and no Torrejon or Cernaysian groups are approximately ancestral. They must therefore have undergone a long course of evolution in some region cut off from Europe and North America. Since the close relations between their Basal Eocene faunæ indicate that these two continents were connected at the end of the Cretaceous, and their most probable connection was by way of the north polar region, the isolated continental region in which the Perissodactyls, Artiodactyls, and Primates developed must have been elsewhere than circumpolar, and the most plausible solution would seem to be that Asia was not connected with the circumpolar land until the Lower Eocene, and that its vast extent furnished an arena for evolutionary struggles, which then, as in later epochs, gave room by its greater magnitude for development a larger number of dominant types than any other part of the world. I have not ventured to embody this idea in the map, as the evidence seems at present inadequate.

2. *Eocene.*

During the Eocene the sea again invaded the continental areas, insulating the six great land masses of North America, South America, Australia, Africa, Asia, and probably Europe. Each continent then developed its peculiar fauna, independent of all the others. This was probably an epoch of warm, moist, and uniform climates, dense forests prevailing over large areas, and the animals were mainly adapted to these conditions. In North America the Uintatheres, the Camels, the Titanotheres, the Horses, and certain peculiar types of Rhinoceroses were among the large animals; in South America the Pyrotheria, Toxodonts and Typotheres, Astrapotheres, Litopterna, Edentates, and other groups of peculiar animals now almost all extinct. Many of these had probably commenced their differentia-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tion during the Cretaceous period, either in South America or Antarctica, and a few of the Edentates may have come up into North America at the close of the Cretaceous and given rise to certain aberrant Edentate forms found in the Eocene of this country (*Metacheiromys*, Stylinodontidæ).

The Eocene mammals of Africa, only discovered within the past two or three years, were equally peculiar, and among them were the ancestors of the Elephants and the Conies and various groups of animals which are now extinct.

In Europe were Lophiodons, Palæotheres, and other large mammals, but the greater part of this continent was at this period, and continued to be through most of the Tertiary, a shifting archipelago of islands whose relations to each other and to the Asiatic continent were continually changing, and the true course of the evolution of its animals is a much more complicated problem than in the other continents.

The Eocene animals of Asia and of Australia are not known, but it may be inferred from the later faunas that each continent was developing its own peculiar mammals, in Australia, the Marsupials, while in Asia may have been evolving the ancestors of most of the more modern groups of mammals.

The map represents the supposed conditions of isolation which favored the development of distinct faunæ in each of the great continental regions. These would seem to have reached their culmination in the Middle Eocene. The Lower Eocene fauna of Europe and North America, derived in part from the pre-existent faunæ of those continents, and in part, as we have seen, from an unknown common source, possibly Asiatic, were a great deal alike, and several genera are common to both regions (*Coryphodon*, *Pachyæna*, *Palæonictis*, etc). But from this time onward the two faunæ developed on divergent lines and no further interchange or migration took place until the end of the Eocene. In America the Perissodactyls developed into *Palæosyops* and *Hyrachyus*, *Helaletes*, *Isectolophus*, and *Orohippus*, in Europe into *Lophiodon* and *Palæotherium*, *Lophiotherium* and *Pachynolophus*. In America the Amblypods developed into *Uintatherium;* in Europe they disappeared. In America the early Hyænodonts died out; in Europe they developed into *Pterodon* and *Hyænodon*. In America the early Lemurs developed into *Notharctus* and the Anaptomorphidæ and Microsyopidæ; in Europe into the Adapidæ and Necrolestidæ. And so on to the end of the chapter. A number of supposed American genera are recorded from the Middle

Eocene beds of Egerkingen, but it should be remembered that these are Lower Eocene, not Middle Eocene genera (although some also persist into the Middle Eocene of this country), and are mostly founded on fragmentary specimens of uncertain identification. Hence they may be taken to infer a connection between North America and Europe in the Lower Eocene, and the persistence in Europe and in part in North America of certain genera characteristic of the earlier age, after the connection had disappeared.

In South America we have a much more complete isolation. The Notostylops fauna of the Basal Eocene (Cretaceous according to Ameghino) contains only a small element which suggests any near relationship with the northern faunæ. In the succeeding faunæ many new elements appear, but none of them seem to be derived from the earlier Eocene faunæ of the northern continents. Edentates and Rodents are the most important, but their relationship to the Edentate and Rodent elements of the Northern faunæ is evidently remote from their first appearance and we must attribute any common origin to an epoch not later than the end of the Cretaceous. The new elements, together with the old, developed upon parallel lines with the Eocene faunæ elsewhere but were entirely independent of them through the Eocene, Oligocene, and Miocene epochs. The closeness of the parallelism speaks for similar climatic conditions and changes in both northern and southern hemispheres, and is a strong argument for the correctness of the correlation here adopted. As is well known, the most prominent and ablest of the Argentine palæontologists advocate a much greater age for the Notostylops and Pyrotherium faunæ than is generally admitted in Europe and North America, resting their claim especially on the discovery of Dinosaur remains in the same formations, and, in the case of the *Notostylops* beds, in close association with the fossil mammals. The geological and palæontological evidence against this view is presented in Ortmann and Hatcher, and important confirmatory evidence is given by M. Tournouer. Dr. Ameghino has recently replied at some length to the criticisms of the first two writers and maintains very strongly his original view, that the *Notostylops* and *Pyrotherium* faunæ are Lower and Upper Cretaceous respectively.

The Upper Eocene fauna of Africa, recently explored by Andrews and Beadnell, shows evidence of a similar long period of isolation for this continent and points to similar physical and climatic conditions as indicated by a fauna analogous to those of the Eocene in North America, Europe, and South America. That this isolation

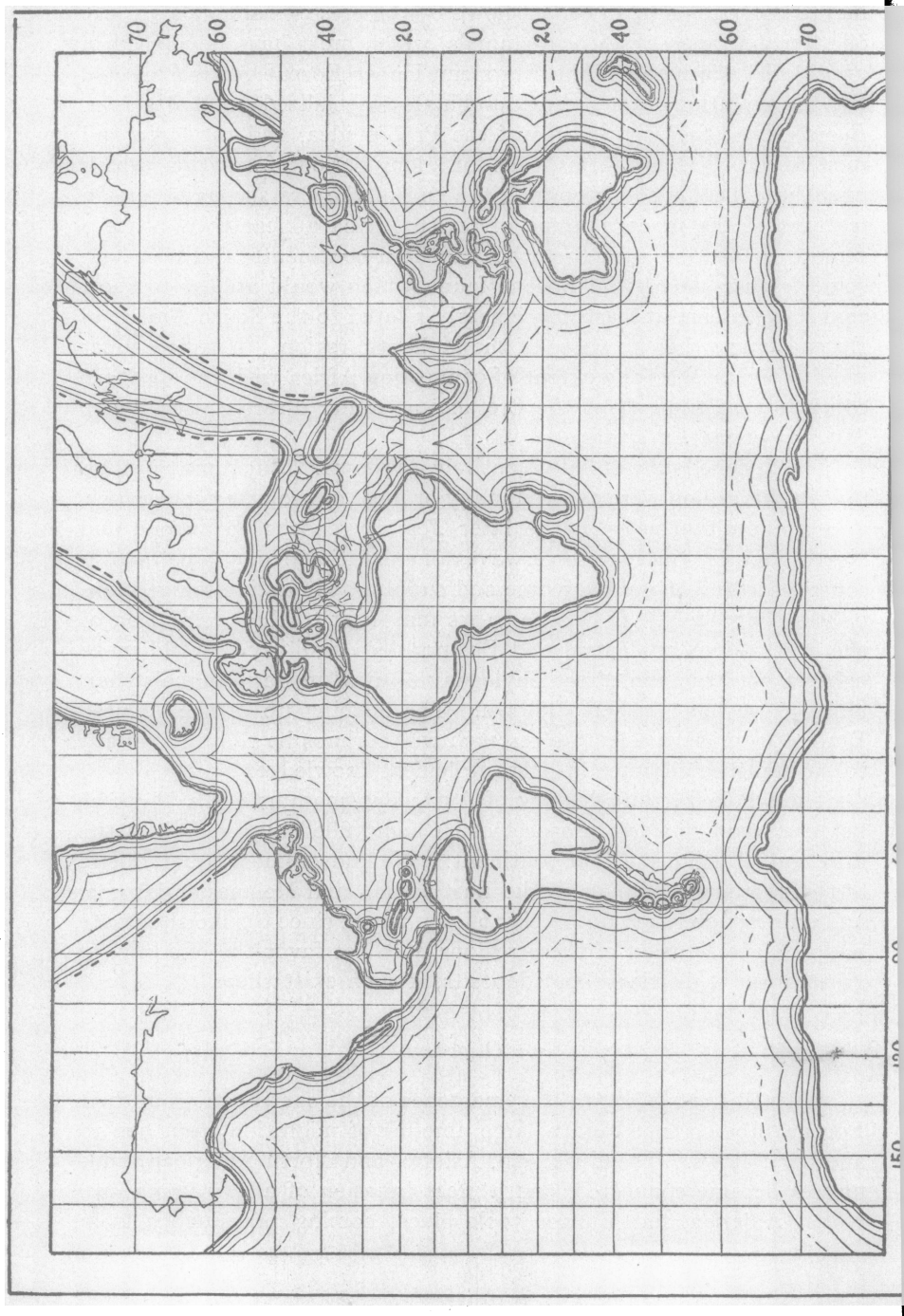
had recently come to an end is shown by the presence among a variety of utterly strange types of mammals, which must have developed in an isolated continent, of the European Upper Eocene genus *Pterodon*. But the evolution of the gigantic and highly specialized *Arsinoitherium*, *Barytherium*, the early stages of the Proboscidea, and the large and remarkable Hyracoid forms, calls for a long period of isolation, which must have begun not later than the end of the Cretaceous. Certain features of the modern fauna of South Africa appear to indicate a remote connection with the other southern continents, and there are some features about the Eocene fauna which would appear to show that it is, in part at least, more nearly related to the South American Eocene faunæ than to those of the Holarctic region. If so, we must modify our ideas to the extent of connecting Africa with the southern continents at the end of the Cretaceous, either directly with South America or via Antarctica.

The Eocene fauna of Asia is entirely unknown. But it may well be that in this region were evolved many or most of the new types which appear simultaneously in the later Tertiary epochs of Europe and North America, in successive waves of migration from some outside source, and in general overcome and supplant the native faunæ more or less completely. If this be so we may look to the exploration of the arid regions of Central and Eastern Asia as likely to yield more light on the true and direct phylogeny of most modern animals than all that we have hitherto known. The opening up of the Chinese Empire to modern scientific research will perhaps be the preliminary to an immense advance in palæontological knowledge.

The whole Tertiary history of Australian mammals is a blank as yet, but there is a fair prospect of its being filled by research in the arid central regions of that continent. We know almost equally little of the Tertiary mammals of the East Indian and Melanesian islands, and unfortunately are not likely to learn much, since the moist climate and dense vegetation of these regions does not favor the exposure of great areas of Tertiary land deposits, if such exist there.

3. *Oligocene.*

With this epoch begins the emergence of the continents from their Eocene submergence, and a large amount of migration from one to another follows. The European, Asiatic, and North American land-masses became connected, and a great invasion of a new fauna into North America and Europe took place, coming presumably from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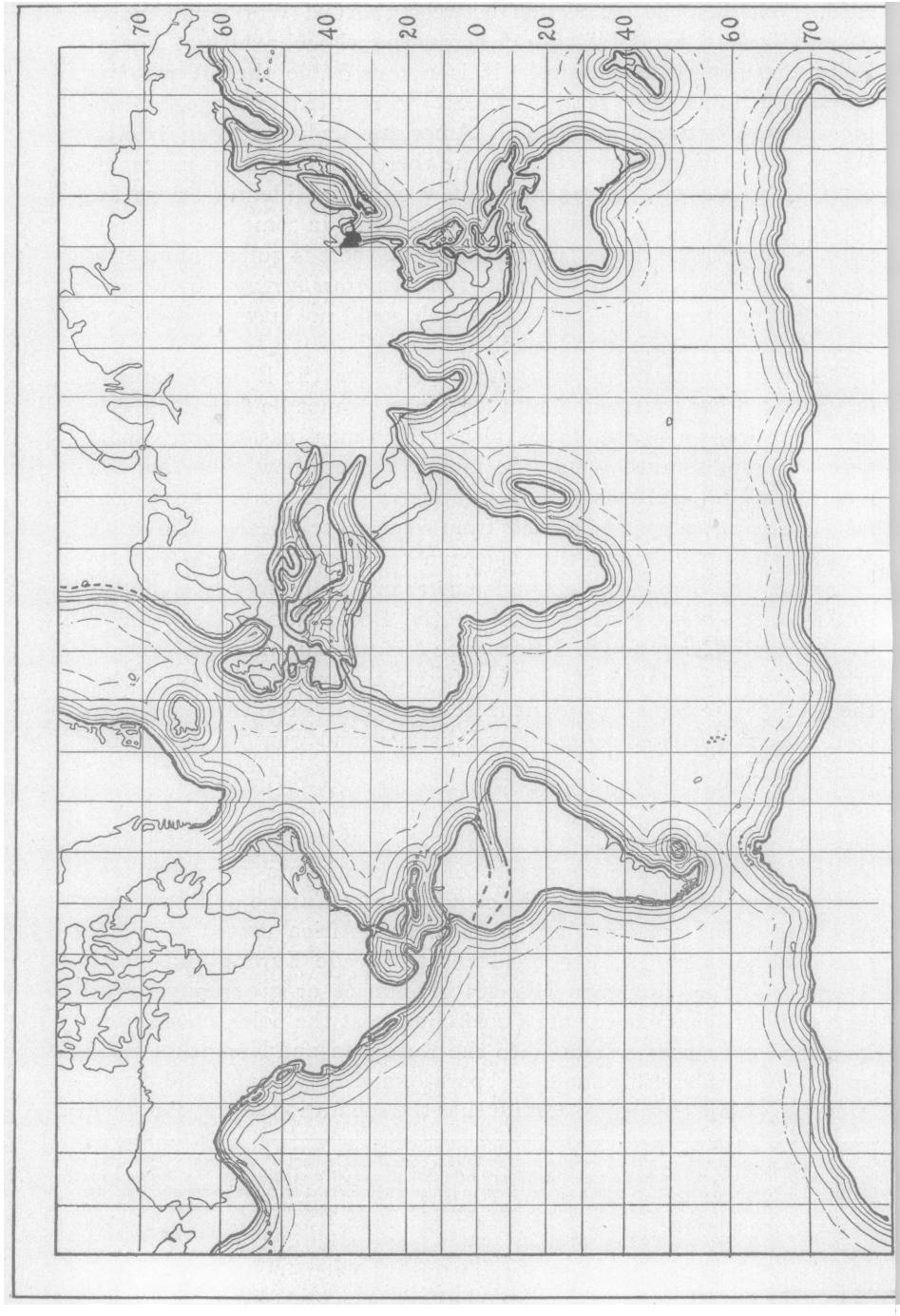
Asia. Whether the connection between the Old World and North America was by way of Alaska or across the whole breadth of a great Polar continent is uncertain.[1] It is not probable that it was via Greenland, for a deep sea intervenes. It resulted in a marked approximation between the North American and European faunas. While in the Middle and later Eocene there is no genus of mammals common to the two continents (a few supposed identifications are based on exceedingly fragmentary material and in some cases I know them to be wrongly made), in the Oligocene there is quite a number of common genera, including *Titanotherium*, *Anthracotherium*, *Elotherium*, large highly specialized Ungulates which could not have passed from one to the other except by a land bridge.

The new faunæ are in part outgrowths from the Eocene faunæ of one or the other continent, but a large part cannot be traced directly back into known Eocene types, although in most cases approximate ancestral representatives may be found. These new types may be regarded as in part descended from unknown elements in the Eocene faunæ, but in part as immigrants from some other region—Asia or the Arctic regions. Through the Oligocene the tendency would seem to be rather for divergence of the faunæ than any further interchange. In Africa the contact at the end of the Eocene does not seem to have persisted long enough to introduce African mammals into Europe, or to destroy the native Ethiopian fauna by countermigration from the north, since certain types at least continued. The three southern land masses remained separate and distinct, and went on developing their peculiar faunas.

4. *Miocene.*

In the Miocene the emergence of the continents had progressed further, and especially the great central sea of Europe and southern Asia had been much reduced in size, and Africa united with the mainland, allowing the Proboscideans to invade Europe and North America. Other unknown changes of climate or geography, quite probably the commencement of cold climate at the poles, caused new invasions of a common fauna into the European and North American areas. Australia still remained separate, and so probably did South America, although it is not certain that the separation was at Panama.

[1] It would appear from more recent research that a considerable part of the Arctic Ocean is of great depth. If, then, we apply here the theory of the comparative stability of the deep oceans during the Tertiary period, to which these maps in general conform, the polar connections of the northern continents must have been much more limited than is represented on the maps, perhaps chiefly by way of Alaska.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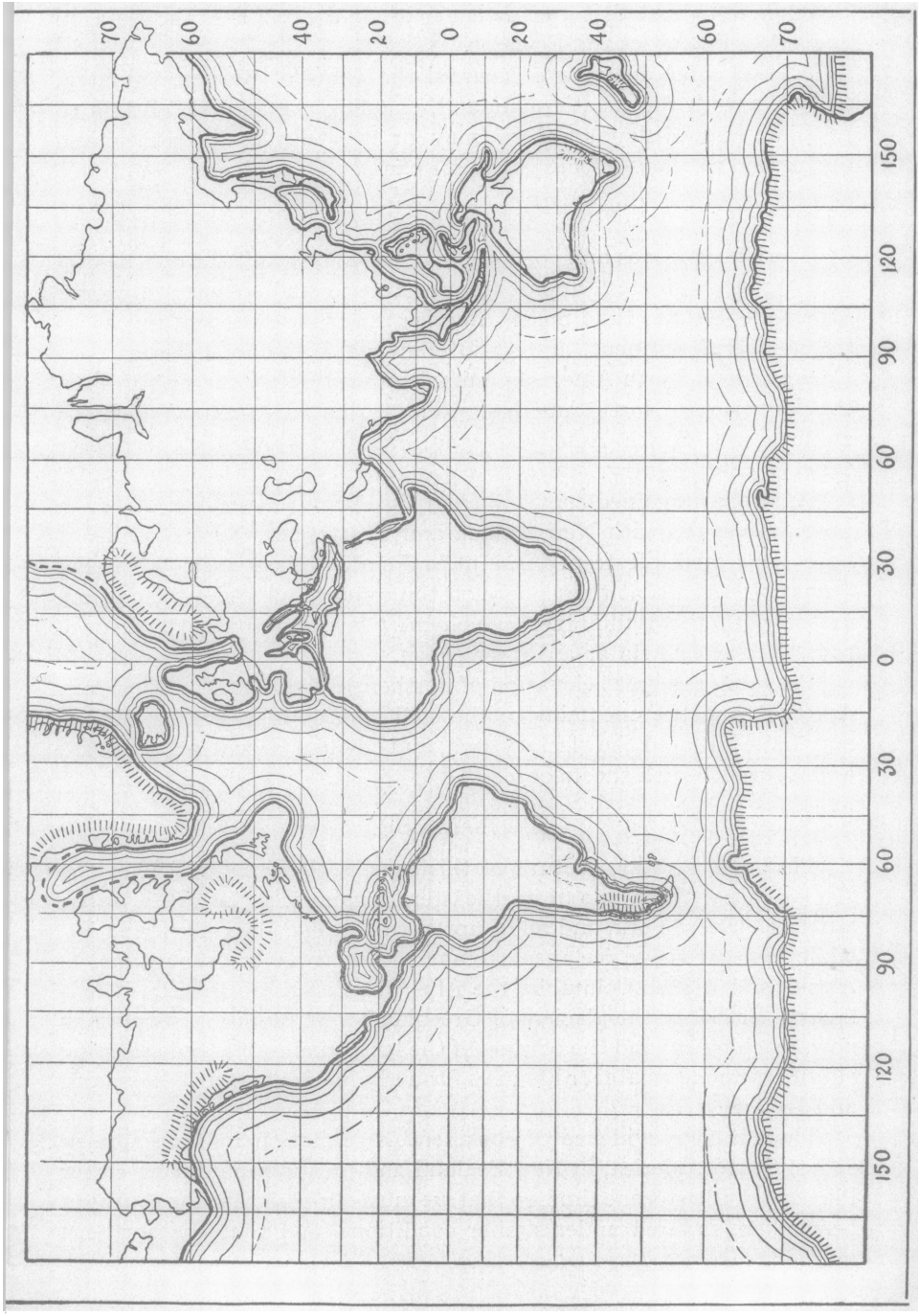


5. Hypothetical Continental Outlines.—Pliocene.

Possibly, as indicated, it was further south, in the region of the Amazon and across the Andes and Ecuador.

At this epoch may have occurred the union of Borneo, Sumatra, and Java with the Asiatic mainland, enabling the animals of Asia to populate these islands. They may or may not have been united during the previous epochs; of this I can get no evidence.

5. *Pliocene.*

The Pliocene was an epoch of great elevation of all the continental land masses, greatest apparently in Europe and in eastern North America. By this time South America must have become united to the northern continent, and an interchange of mammal faunas took place, various South American animals appearing for the first time in the Pliocene of North America, while a great invasion of northern animals into South America began, rapidly displacing the native types of that country.

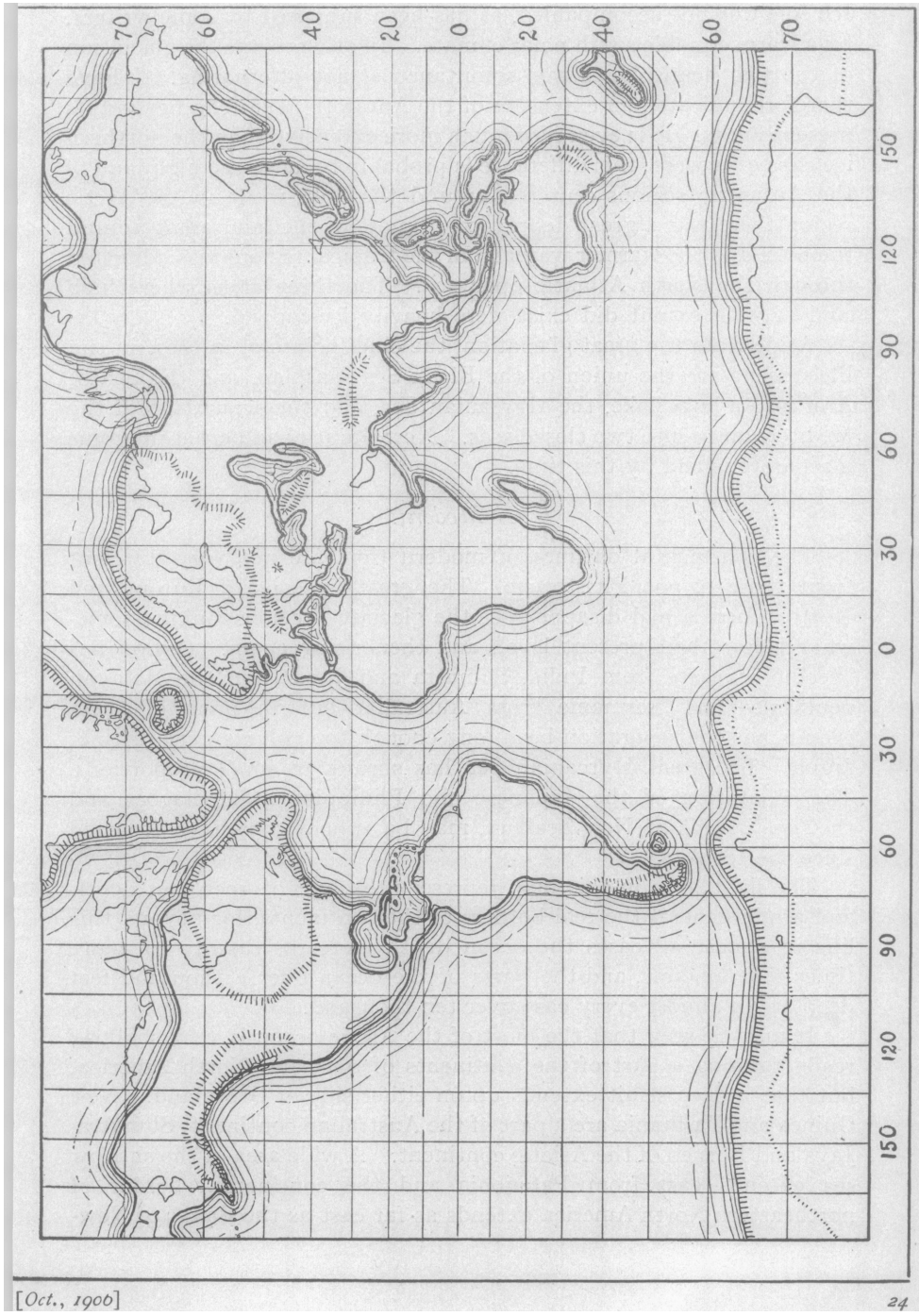
Australia remained separate from the Asiatic mainland, although probably united with New Guinea and Tasmania. Borneo seems to have separated off from Asia at an earlier time than Java and Sumatra, perhaps at this epoch; on the other hand it may have been united with the Philippines, which may be supposed to have been connected with Asia at a former epoch.

Probably the great elevation of northern Europe and northeastern America, and the oncoming of the cold climate in the polar regions may have initiated the glacial epoch, and covered Greenland, Norway, and Labrador with sheets of ice.

6. *Pleistocene.*

The most striking feature of this map is the culmination of the glacial epoch, the whole of northeastern America, as far south as the latitude of New York, and all of northern Europe, being buried in ice, while less extensive ice masses came down from the mountains of Alaska and British Columbia, the Alps, the Caucasus, and the Himalayas. Probably the glaciers of Greenland were more extensive than now, reaching beyond the borders of the land on all sides, and sweeping out of existence whatever life may formerly have inhabited Greenland and Iceland.

There is clear evidence of considerable glaciation in the southern end of South America, in New Zealand and in Australia during either Pliocene or Pleistocene time, so that we must suppose that the southern hemisphere suffered under similar conditions, and that the northern



6. Hypothetical Continental Outlines.—Early Pleistocene.

Ice Age was not accompanied, as has been supposed by some writers, by a warm equable south polar climate. In other words the glaciation of the two hemispheres was simultaneous, not alternating. I have therefore indicated an extension of the Antarctic polar cap beyond its present limits. It is even now much more extensive than the northern ice caps ever were; this difference is probably because the high land of the Antarctic regions centered around the pole, while in the Arctic region there was a great depression of most of the land areas around the pole, and the warmer water from the tropical regions was admitted through the North Atlantic open sea. The three areas where high land of wide extent did exist were heavily ice-capped.

Aside from the great glaciation, the chief points of interest in the Pleistocene are the union of the Black Sea, Caspian, and the Sea of Aral into a huge lake, the Hyrcanian Sea, and the separation of the Mediterranean into two closed seas. New Guinea had perhaps become a separate island by this time.

7. *Modern.*

The continental outlines of modern time are not very different from those of the Pleistocene. The great ice-caps of Europe and North America had disappeared, the glaciated regions sinking somewhat below their present level, and then rising again. Ceylon has become separate from India, Sumatra and Java from the Malayan peninsula, and Tasmania from Australia; but in none of these islands has the separation been long enough to evolve a very distinct fauna. The great Hyrcanian Sea has shrunk to small proportions. The separation of the Japanese and Philippine archipelagoes and the two islands of New Zealand, may be supposed to have occurred since the Ice Age.

The light lines in this map represent the line of 1000 feet depth and are in general the real borders of the continents, for beyond this line in almost all cases the ocean depth increases rapidly to many times that amount, and the parts of the ocean over a thousand feet deep are in almost every case over ten thousand.

It may be seen that the most of the Arctic ocean is very shallow, really forming a part of the continents of Asia and North America, but that a deep strait extends up on either side of Greenland. New Guinea and Tasmania are a part of the Australian continent; Sumatra, Java and Borneo of the Asiatic continent. A wide area of the shallow sea extends east from Patagonia and the continental border of northeastern North America extends as far east as the Banks of New-

foundland. Alaska and Asia are connected by shallow water, England and Ireland are a part of the European continent mass, Japan of the Asiatic, while the Philippines connect with Borneo, and so on. On the other hand, New Zealand, Madagascar, Celebes, Iceland, and many smaller oceanic islands, have no shallow water connections. These relations are one principal guide in constructing former geologic connections, as it is evident that a slight rise in the land would unite for instance Sumatra to Malacca, while it would take a great geological convulsion to unite New Zealand to Australia, and such an upheaval ought to leave recognizable traces.

III. Regional Notes.

Europe and Adjoining Regions.

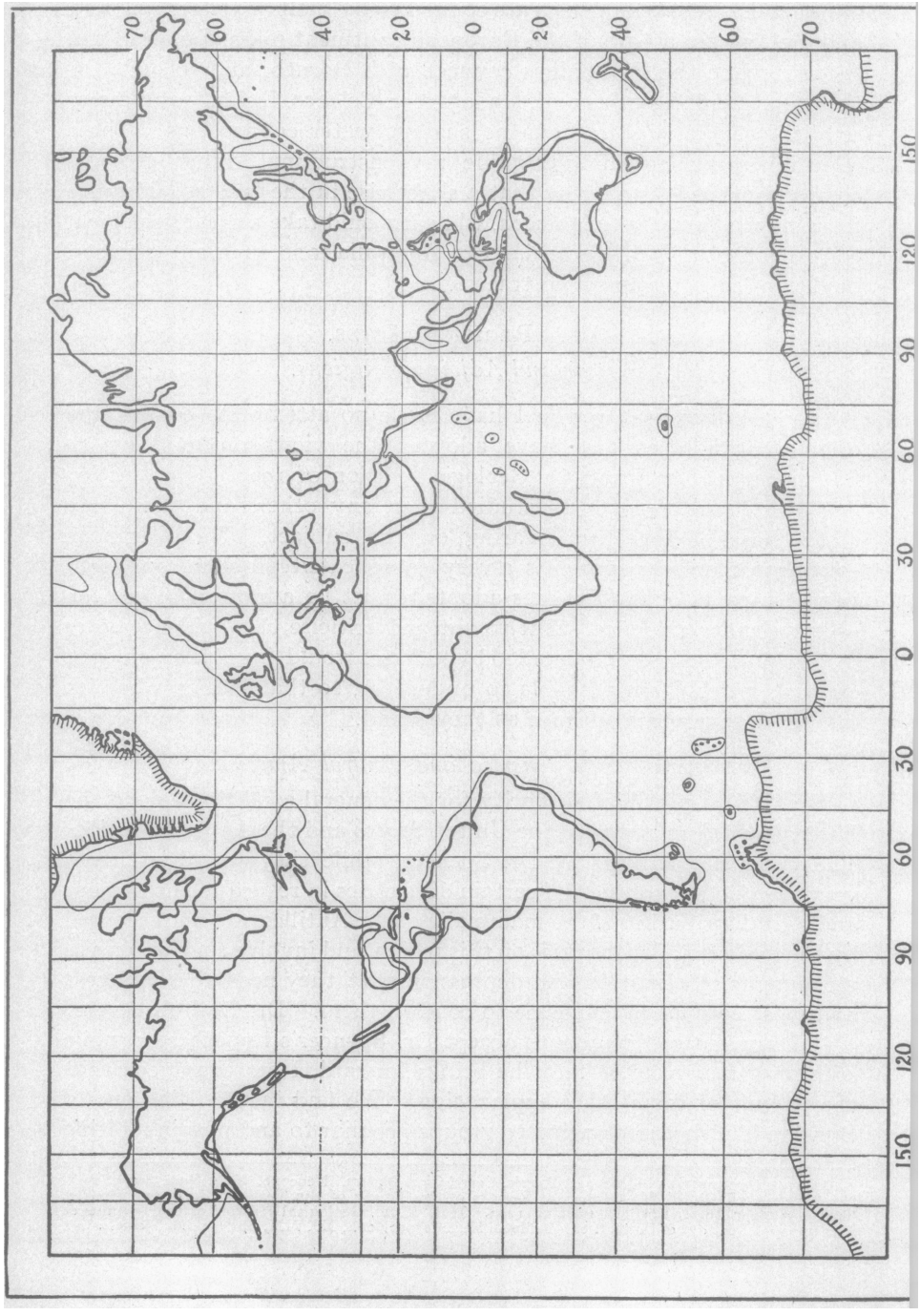
For the European region I have made no attempt to consult the original authorities, but have adopted the views outlined by de Lapparent in his 'Traité de Géologie,' edition of 1900. This section has been more thoroughly studied than any other, and there is a great mass of literature bearing on the subject. The European continent, however, presents a very complicated problem, and considerable parts of the outlines adopted must be admitted to rest on pretty slender evidence. But to sift and criticise this evidence so as to eliminate the less well founded hypotheses would involve an amount of work which I am not able to undertake, so that it seems best to take de Lapparent's outlines as they stand.

Eastern North America and Central America.[1]

Dr. Dall is my chief authority for the general conditions along the Eastern and Gulf coasts of the United States and the Antillean region. The views propounded by Dr. Spencer, while they would supply a very satisfactory solution of certain difficulties in regard to the present and past distribution of the mammalia of the Antilles, are not accepted by the majority of authorities on this region, and involve such extensive movements of elevation and depression that they need the strongest and most convincing evidence to confirm them. Dr. Dall observes:

"I am entirely unable to accept Dr. Spencer's hypotheses; while admitting many of the facts he brings forward, I am convinced that they admit of some other explanation. We find in the Oligocene of Bowden landshells belonging to groups peculiar to and now inhabiting

[1] Chief Authorities:—Dall and Harris, Correlation Papers. Neocene. U. S. Geol. Surv., Bull. No. 84, 1892. Dall, W. H., Geological Results of the Study of the Tertiary Fauna of Florida, Trans. Wagner Inst., Vol. III, part vi, 1893. Hill, R. T., Geological History of the Isthmus of Panama and Portions of Costa Rica. Bulletin Mus. Comp. Zoöl., XXVIII, pp. 151–285, June, 1898.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the island of Jamaica, which is sufficient evidence that since the era during which the Bowden marl was deposited the island has never been entirely submerged. With Cuba it may be different, although I can hardly bring myself to believe that the peculiar landshell fauna which is so characteristic of that island can have been evolved since the Pleistocene . . . but that any considerable part of the island has been submerged since the beginning of the Miocene seems extremely doubtful. . . . According to Mr. Vaughan's observations the great mass of the Tertiary limestones of Cuba are middle and upper Oligocene. . . . The Vicksburgian and the Miocene are alike absent, no positive identification of Pliocene beds has been made, and the Pleistocene reef rocks do not occur above the sea at a greater height than thirty or forty feet.

"The, on the whole, remarkable horizontality of the Floridian strata indicates a freedom from violent changes of level from the time the Peninsular limestone first emerged from the sea. Landshells in the Ocala limestone show that then dry land existed. South of the Suwannee Strait, closed in late Miocene times, there is no evidence of subsequent submersion to any serious extent. Two gentle flexures run parallel with the peninsula, having the lake district between them; a tilting of, at the most, thirty feet, up at the east, down at the west, which may have been contemporaneous with the flexures; and, for the rest, very slow and slight but probably nearly continuous elevation never exceeding one hundred feet and perhaps less than half that, with dry land and fresh water lakes constantly existing since the Ocala islands were raised above the sea; such is the geological history of the Florida peninsula. . . .

"On the Gulf and southeast Atlantic coast of North America no marked stratigraphic break has been established between the Eocene and Oligocene series. . . . Nevertheless if the invertebrate fauna is taken into account and all allowances made for the existence of a few indications of transition, the change in the fauna is so marked that physical changes elsewhere must be assumed to account for it. . . . The thickness and extent of the Vicksburg limestone, stretching from the Floridian region to Costa Rica, and its singular absence from the Antilles, so far as yet identified, taken together with the comparative thinness of the post-nummulitic Oligocene on the Gulf coast and its enormous development in the Antillean region, the north shore of South America, and the region of Middle America south of Mexico, suggest that during the period indicated there was first a depression of the continental border coincident with elevation

of Antillean lands, while during the period of the upper Oligocene these conditions were reversed, the continental sea margin being brought near to, and even, at the Ocala Islands, above the surface of the sea, while a depression of Antillean lands and Middle America permitted the formation of those great bodies of marine limestone and marls for which the upper Oligocene of those regions is so remarkable. . . . [At the close of the Oligocene] the Middle American highlands, the larger Antillean islands, and the peninsular island of Florida were uplifted, the two Americas united, and vast physical changes consummated. Coincidently at the north the boreal coasts were gently depressed and the waters of the Miocene sea extended over the ruins of the Oligocene forests. . . . Some change along the northern coast permitted an inshore cold current to penetrate the Gulf, depositing on the floor of the shallow Suwannee Strait separating the island of Florida from the continental shore, a thin series of Miocene sediments. . . .

"The movement in elevation which ushered in the Miocene continued, probably, during its entire term. It amounted in Costa Rica, according to Gabb, to several thousand feet, and permanently united the two continents.

"I concur with Hill in the belief that whatever changes of level may have taken place since, no discontinuity of the link between North and South America from the Miocene to the present time is probable, and certainly none amounting to a free communication between the two oceans.

"At the termination of the Miocene epoch Florida became united to the continent."[1]

Dr. Dall explains the fact that the Texas Miocene fauna is of a different stamp from that of the eastern Gulf and Atlantic coasts, but nearly allied to that of the Pacific coast, by the supposition that the fresh water of the Mississippi pouring into the Gulf served as a barrier to the westward migration of species of marine invertebrates.

Dr. Hill summarizes his views in regard to the Central American isthmus as follows:

"There is considerable evidence that a land barrier in the Tropical region separated the two oceans as far back in geological history as Jurassic time, and that that barrier continued throughout the Cretaceous period. The geologic structure of the Isthmus and Central American regions, so far as investigated, when considered aside from

[1] Trans. Wagner Inst., III., pt. vi., pp. 1545, 1547, 1549, 1550.

the paleontology, presents no evidence by which the former existence of a free communication of oceanic waters across the present tropical land barriers can be established. The paleontologic evidence indicates the ephemeral existence of a passage at the close of the Eocene period. All lines of inquiry—geologic, paleontologic and biologic—give evidence that no connection has existed between the two oceans since the close of the Oligocene. This structural geology is decidedly opposed to any hypothesis by which the waters of the two oceans could have been connected across the regions in Miocene, Pliocene, Pleistocene, or recent time."[1]

In the above summary Dr. Hill takes no account of the evidences from fossil land vertebrates, nor does he mention them in his discussion of the evidence on which his conclusions are based. Nevertheless they give some of the most important data on which the question should be decided, for the stratigraphy is as yet too imperfectly known to be decisive on all points. In the main the evidence from fossil mammals very strongly confirms his conclusions, but points to a longer duration of the early Tertiary break between the two continents than he is disposed to allow. The Middle Miocene (Santa Cruz) land vertebrate fauna of Patagonia and the Middle and Upper Miocene fauna of the Western States are among the best known and most extensively explored and studied of all our fossil faunas. Each points to an absolutely independent development which must have endured for a long time. No South American types appear in North America, no North American types in South America, until the beginning of the Pliocene. In the Pliocene (Blanco) a number of South American types appear, for the first time, and continue to appear through the Pleistocene, a few still existing. At the same epoch in the South American formations (Araucanian) appear for the first time North American types, and they increase in proportionate numbers until recent times, gradually displacing the autochthonic types, most of which are now extinct.

It is hardly possible to suppose that if land mammals had free communication between the northern and southern continents as early as the close of the Oligocene, not a single species extended its range from one to the other continent until the beginning of the Pliocene, but that a large interchange of faunas then suddenly commenced. Stable conditions would not account for such a fact, for the conditions were not stable, as is shown by the rapid evolution of

[1] Bull. Mus. Comp. Zoöl., XXVIII., p. 270

many mammal races and the immigration of many new types in the North American Miocene. Some barrier there must have been; it could hardly have been a climatic barrier, for that would have hindered the interchange of faunas during later epochs as well as in the Miocene. No other hypothesis but that of a continuance throughout the Miocene of the separation of the continents appears to be applicable. The entire continuity of the isthmus after the Oligocene, rests on the absence of Pacific types in the marine Gulf sediments of the Oligocene and Miocene epochs. How far this fact might be explained away by differences in temperature of the waters, or other limiting conditions, I am unable to say. But most land mammals are certainly much less subject to limitation of range from conditions of temperature or climate than are marine invertebrates, and it appears to me that their evidence ought to have much greater weight, when it is derived from sufficient data, as in this case it is.

It is quite true, as Dr. Hill remarks, that the separation of the continents need not have been at Panama, but elsewhere along the Central American strip. Dr. Ortmann has suggested, as a mode of reconciling the conflicting evidence from vertebrates and invertebrates, the adoption of Von Ihering's hypothesis, that South America was divided into two areas during most of the Tertiary period, by a strait reaching up the present Amazon valley and through to the Pacific across what is now one of the highest and broadest parts of the Andes. This would more or less reconcile the evidence from our present knowledge of the mammalia, as no Tertiary mammal fauna is known from the area north of the Amazon. I do not know whether the distinctness of the Tertiary invertebrates of the Pacific and Gulf coasts would accord with an oceanic connection across South America much better than with one through Central America. But the hypothesis involves such a staggering amount of elevation since the beginning of the Pliocene, that one would hesitate to accept it on the palæontological evidence alone, and the stratigraphic proof appears to be at present inadequate. If we knew the Tertiary and especially the Miocene faunas of Venezuela and Guiana better the hypothesis could be tested by them; without that, it is too radical for the present view.

The authors of the Neocene ' Correlation Papers ' summarize their conclusions on this subject as follows:

"Toward the end of the Eocene it is certain that the process of elevation had proceeded far enough to raise above the sea part of the summit of the western anticline of Florida, if not of both the great Floridian anticlines. . . . At the end of Eocene time the con-

tinental shore line appears to have bordered the Atlantic in a generally northeast and southwest direction from the Hudson to the Chattahoochee. . . . There was a well marked indentation in southeastern Georgia, while from the vicinity of the Chattahoochee the shore rounded to the west, northwest, and north, forming the eastern coast of the great Gulf of Mississippi . . . which extended to the meeting of the Ohio and Mississippi rivers. . . . From this vicinity the shore extended in a southwesterly direction, without striking irregularities, to the Rio Grande. At the culmination of the Eocene a movement of elevation seems to have taken place, which, . . . raised this shore to an extent which gave the continental margin a notable addition to its area. . . . The most important additions in point of area were to the southwest and on the shores of the Gulf of Mississippi. The area between the central Florida banks and the mainland was not elevated above the sea. . . . After the end of the older Miocene, the Floridian banks and their associated islands still remained insulated from the continent. . . . Before the termination of the marine Pliocene the permanent connection of the peninsula [Florida] with the continent was accomplished." [1]

Dr. Becker summarizes the conditions during the Tertiary thus:

"Both the Sierra Nevada and coast ranges were above water during the interval between the Knoxville and the Chico epochs. Both ranges sank just before the beginning of the Chico, admitting the ocean over a great part of the coast ranges and over considerable areas at the base of the Sierra. Both appear to have risen partially and gently before the Tejon (Eocene) particularly toward the north. . . . A slow subsidence would seem to have taken place before the Miocene. . . . indicating for the Miocene a lower general level than during any preceding epoch. During the Pliocene very little of either range was below water." [2]

Greater Antilles.[3]

Dr. Hill's (*l.c.*, p. 224) results are summarized as follows:

"The land débris constituting the Eocene strata throughout the islands testifies the pre-existence of extensive Cretaceous land areas. There was a profound regional subsidence in late Eocene and early

[1] Dall and Harris, Neocene of North America. U. S. Geol. Surv;, Bull. 84. pp. 181, 182 186, 191.

[2] Becker, Tertiary and Post-Tertiary Changes of the Atlantic and Pacific Coasts. Bull. Geol. Soc. Am., 1891, p. 323.

[3] Chief Authority:—Hill, R. T. Geological Reconnoissance of Jamaica. Bull. Mus. Comp. Zoöl., Vol. XXXIV, 1899, pp. 1-226.

Oligocene time, which submerged all but the highest tips of the Antilles. . . .

"In late Oligocene or Miocene time there was a tremendous orogenic movement which resulted in uplift whereby many of the islands were connected with each other, and possibly an insular southern portion of Florida, but not establishing land connection with the North or South American continents.

"In Miocene or early Pliocene time the islands were severed by submergence into their present outlines and membership, which they have since retained with only secondary modification.

"In Pliocene and Pleistocene times there have been intermittent periods of elevation . . . but not sufficient to establish land connections or to restore the islands to the heights and areas of Mid-Tertiary time."

Dr. Spencer's much more radical views in regard to this region are stated in the following paragraphs. The objections to adopting them have already been quoted.

"During early Eocene a portion of the West Indies was elevated, but this elevation does not seem to have extended to the adjacent continental area. During the later Eocene and most of the Miocene period only a few islands appear to have existed in the seas of the West Indies and Central America. . . . In the Miocene period there appears to have been a great subsidence of many portions of the Antillean and continental regions. . . . Throughout most of the Pliocene period there was an extensive elevation and development of the Antillean region. In part this elevation may have commenced in the later Miocene. . . . The great continental elevation in some regions [Barbadoes, Anguilla, Trinidad] appears to have commenced at the end of the Miocene and in other places in the early Pliocene period [Cuba, San Domingo, Jamaica, Florida], but the Tertiary seas were being gradually restricted, from the early Eocene times, along the continental margin. . . . The geologic development of Central America is yet somewhat hypothetical. That the drainage was towards the Pacific is highly probable if not certain, since the characteristics of the adjacent portions of the ocean bed indicate a continuation of the Gulf and Caribbean valleys and plains; but in the great oscillations of the land from abyssmal depths to continental elevations of 8000 or 12,000 feet, some insular masses doubtless rose into prominence. Such heights would refer mostly to the region of the Greater Antilles and the adjacent continents, for the Gulf and Caribbean plains must have been low. . . . The surveys of the

sea of Honduras are much less complete than those of the Gulf of Mexico, but they are sufficient to indicate that a great portion of that sea was shrunken to narrow limits if not entirely drained. . . .

"The Matanzas epoch [about equivalent to the Lafayette, Upper Pliocene] represented a general submergence below the present altitude, not only of the coastal plain from 100 to 1000 feet but that the Antillean lands at the end of the Pliocene period were depressed so that only a few islands remained at altitudes from 100 to 1100 feet lower than to-day. . . . After the deposition of the Matanzas limestone and the Lafayette loams the continent rose to a great elevation. The present lands of the West Indies and the adjacent parts of the continent stood quite as high, if not higher than during the Pleistocene elevation. Whether the elevation was great enough to completely drain the sea of Honduras (as the Caribbean sea) cannot be told at present. The great altitude of the Antillean land is no longer a question. . . . The subsidence (in the later Pleistocene) which followed the earlier Pleistocene elevation. . . . depressed all of the greater Antilles, Central America, and the coastal margins of the continent from about 25 to 500 or 700 feet lower than now. This subsidence greatly reduced the size of the larger West Indies and Central America; it also made the coast of the northern continent recede 100 or 150 miles and drowned most of Florida. . . . At the close of the Pleistocene the Antilles rose from 150 to 200 feet above the modern altitude . . . the floor of the Antillean seas . . . were low lands extending to the Pacific side of Central America [during the Pliocene elevation] but it is to be remembered that this inference is tentative only. . . . The modern islands of the West Indies formed an elevated plateau bridge between the two Americas during the two epochs of elevation, namely in the Pliocene and Pleistocene periods. . . . The Pacific contours do not support the hypothesis of a post-Miocene extension of the sea of Honduras to that ocean, as do those of the Gulf of Mexico and Caribbean sea. It would appear that the latter basins drained directly into the western ocean in the earlier part of the Pleistocene period. The late Pliocene depression admitted the Atlantic currents with greater depths than at present to the Antillean seas. The Pacific waters probably had access by one or two straits with depths of about 200 feet . . . Panama and Nicaragua. With the earlier Pleistocene elevation the drainage of the Antillean continent was again restored to the Pacific ocean between the barriers of Central America which were now being brought into prominence . . .

turning the Caribbean and Gulf plains into basins which became seas at the end of the [Pleistocene] elevation. The writer is inclined to regard broad submarine plateaux now at depths of 2500 to 5000 feet as terrace plains and terrestrial slopes like the coastal plains of the continent, representing the altitude of the Pliocene continent during a considerable portion of the period. . . . Thus the Atlantic waters were admitted to the region of the West Indies in the later part of the Pliocene period, to be drained off by terrestrial elevation in the early Pleistocene with perhaps a shallow connection with the Pacific in Mid-Pleistocene days, since which time there has been no connection with the Pacific, but free communication with the Atlantic."[1]

Alaska and British Columbia.[2]

The authors of the Correlation Papers, on the evidence there summarized, conclude that Alaska and British Columbia were above water during the Eocene to an extent as great as or greater than now. A submergence during Oligocene and Miocene succeeded, followed by a re-emergence during Pliocene to a higher level than now.

Spurr observes: "The Kenai series [Oligocene] shows that the rocks were formed entirely in fresh water. . . . In the period succeeding the post-Kenai revolution, the greater part of Alaska seems to have been land. . . . We have already seen how the comparatively level interior plateau with its ancient broad, shallow valleys, and mountains greatly reduced by erosion, points to the stability of the land for a long period subsequent to the Kenai revolution. . . . In the same manner the deep canyon-like valleys in which the present streams flow point to a decided and long-continued elevation of the land at the end of this period of stability. . . . We may believe that this elevation took place in late Miocene or early Pliocene times . . ." (*l.c.*, pp. 259, 262).

The Tertiary geology of Alaska and of northeastern Siberia is so imperfectly known that we must depend largely on the evidence from palæontology as to the former land connections between the two. The close resemblance between the Basal and Lower Eocene faunæ of Europe and North America is my chief warrant for assuming an extensive post-Cretacic connection mainly across the present Arctic ocean between Siberia and northwestern North America, and probably includ-

[1] Reconstruction of the Antillean Continent. Bull. Geol. Soc. Amer., Vol. VI, 1895, pp. 103-140.

[2] AUTHORITIES:—Clark, W. B. Correlation Papers, Eocene. U. S. Geol. Surv., Bull. No. 83, 1891. Dall and Harris, Correlation Papers, Neocene. U. S. Geol. Surv., Bull. 84, 1891. Spurr, Geol. Yukon Gold Dist., Alaska. U. S. Geol. Surv., Ann. Reps., 1896–7.

ing the northern half of Bering Sea as far as the border of the continental shelf. The spread of the Camels into Asia, Africa and Eastern Europe in the Pliocene, and the many other faunal interchanges of that epoch, warrant the assumption of a Pliocene connection, and the repetition of these interchanges in the Pleistocene allows us to suppose that the connection was either continued or repeated early in that epoch. During the greater part of the Eocene the trend of evolution among the mammals in the two continents appears to have been a development of the autochthonic faunas; this may be taken to indicate, although it does not prove, a separation during this time. At the end of the Eocene and beginning of the Oligocene and again in the middle Miocene occur marked approximations in the faunal development of Europe and America. Many new types appear, which are much more closely related than were their predecessors. In some cases the genera are identical (*Titanotherium*, *Anthracotherium*, *Didelphys*, *Sciurus*, *Steneofiber*, *Cynodictis*, *Elotherium* in the White River Oligocene, *Dipoides*, *Amphicyon*, *Mustela*, *Potamotherium*, *Lutra*, *Trilophodon*, *Aphelops*, *Palæomeryx* in the Middle and Upper Miocene). Others are very closely related in the two continents. No identical genera are known to occur in the Middle and Upper Eocene of Europe and America. The few identifications that have been made of European fossils with American genera are based on very fragmentary materials and are certainly erroneous in some cases. These facts indicate a much closer connection between the continents after the Eocene, the mammals interchanging by way of Alaska and the circumpolar lands or pushing southwards from a common boreal center. For the purposes for which these maps were designed it is convenient to assume a continental connection at Alaska. The southern mountainous section of this region is the newest part of the territory and I have not included it in the connection, but have run the old coast line along the border of the continental shelf, through the middle of Bering Sea, cutting out the Aleutian peninsula and islands as a volcanic ridge of comparatively recent formation.

Southern Hemisphere.

In regard to the southern hemisphere I have adopted in the main the views of Ortmann and Hatcher, especially as to the age of the Patagonian Tertiary horizons, and incidentally as to the probable age of much of the Australian and New Zealand Tertiary. These authors consider the marine Patagonian formation which underlies a large

part of the Patagonian plains as Lower Miocene. The continental subsidence which must have partly preceded the laying down of this formation I have thought best to represent on the Oligocene map, and to represent on the Miocene map the subsequent elevation which enabled the æolian Santa Cruz formation (Middle or Upper Miocene) to be deposited up to and beyond the present shore outlines. A slight subsidence of the southern end of the continent in the Pliocene epoch is indicated by the Cape Fairweather beds, followed by a Pleistocene elevation, probably not very great, during which the fluviatile-æolian Pampean formation was laid down and the present topographic features mostly completed. The northward extension of the glaciers of Tierra del Fuego is regarded as occurring in Pliocene and Pleistocene; here, as in Australia and New Zealand, the exact epoch of glaciation appears to be still uncertain.

The most important point illustrated in the southern continental outlines, is the connection of South America and Australia with the Antarctic continent. This is generally regarded as having occurred at the end of the Cretaceous or the beginning of the Tertiary period. There appears to have been shallow-water archipelagic connection with New Zealand as well, probably via New Guinea, according to Hedley. There is no evidence to show that these connections were simultaneous, but it is convenient to represent them so on our map and to place them in the post-Cretaceous. During the entire Eocene, Patagonia continued to be elevated above its present level, various local fluviatile or æolian deposits representing different parts of this epoch, and Ortmann thinks that a shallow-water connection with Antarctica persisted into the early Tertiary.

The connection of Antarctica with Africa, at least during the time covered by this series of maps, is regarded by Ortmann as very doubtful, and it seems best to omit it here, as the series is intended to represent a somewhat conservative view.

For the former outlines of Australia and New Zealand, Hedley and Tate are my principal authorities, but some of their conclusions are modified in accordance with Ortmann's criticisms.

The proper correlation of the Tertiary deposits of the southern with those of the northern hemisphere is a difficult problem, and very discordant views have been expressed by different authors, especially as regards the Patagonian formations. Dr. Ameghino, to whose diligent and untiring researches is due most of our knowledge of the great Tertiary mammalian faunas of Patagonia, correlates the various horizons with considerable older epochs, and his views are accepted wholly or in

part by Moreno, Mercerat, Roth, von Ihering and other South American geologists. But Mr. Hatcher's unequalled practical knowledge of the Mesozoic and Tertiary fossil fields of the interior of North America makes his views as to the stratigraphy of the corresponding formations of Patagonia, based on his explorations there in 1898–99, of peculiarly high authority, and Dr. Ortmann's correlation of the marine formations by their invertebrata is based on researches much more extensive and elaborate than any yet made. Recent observations on Patagonian stratigraphy by M. Tournouer seem to accord in the main with Hatcher's views. In accepting these stratigraphic views I am far from wishing to ignore or belittle the splendid palæontologic work of Dr. Ameghino, which when properly coördinated with the work of the great body of observers in the northern continents, will most certainly greatly extend our knowledge, and broaden our understanding, of the evolution of the Tertiary mammalia. The completion of the elaborate studies now being made by Professor Scott, with the assistance of Dr. Farr and Mr. Sinclair, of the fossil collections obtained by the Princeton and American Museum expeditions to Patagonia, will be a great step towards such coördination, and to the publication of their results we look forward with much interest.

For the remaining areas I have depended partly on de Lapparent and other writers already quoted, and very largely on Lydekker's 'Geographical Distribution of Mammals.' The evidence is in most cases derived chiefly from the modern faunas of the different regions, for little is known of their geology and almost nothing of their fossil mammals.

The supposed continent of Lemuria I have omitted except to indicate its possible pre-Tertiary existence in the string of islands connecting Madagascar with India. The various mid-Atlantic continents that have been suggested may likewise be relegated to pre-Tertiary time as there is no adequate evidence of their existence within the Cenozoic.