PALÆOGEOGRAPHY AND POLAR SHIFT*

A Study of Hypothetical Projections.

BY

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INTRODUCTORY NOTE

我知天下之中央，燕之
北，越之南，是也。(惠施)

"I know the centre of the world:
it is north of the North (Yen)
and south of the South (Yueh)."*

HUI SHIH (ca. 380-300 B.C.)

When first asked to write a paper for inclusion in the Grabau Anniversary Volume of the Bulletin it was but natural that the fascinating topic of palæogeography should suggest itself as one appropriate to the occasion, since it has been in this field that Dr. Grabau's classic contributions have most directly influenced the development of Cenozoic research in China.

Ever since my first attempt to discuss the subject of primate dispersal from the point of view of palæogeography,[1] efforts have been made to add to the scanty data then presented on past and present primate distribution. It is now hoped that with the cooperation of scientists abroad, other workers more skilled in the field of bibliographic record will soon compile a complete bibliography of fossil primates on which further and more detailed studies of past distributions may be based. Up to the present, however, the additional information I have been able to accumulate on the subject since 1925 is such as to modify in no very fundamental way the general conclusions on primate dispersal then expressed.

On the other hand some of the various outline maps which have been constructed during that interval would seem to be worth while reproducing and discussing on the present occasion, since they illustrate certain possibilities of past geographic conditions not evident in ordinary projections. Before

* The subject of polar shift being raised during a recent conversation with Professor Hu Shih, he immediately quoted this delightfully apt ninth paradox of Hui Shih, and he has subsequently very kindly furnished me with the correct text and translation of the passage so that it might be quoted here. A short but most interesting biographical note on Hui Shih, statesman and the friend of Chuang Tze, together with a list and discussion of his famous paradoxes, will be found in Part III, Book III, Chapter V, of Professor Hu Shih's well known work, "The Development of the Logical Method in Ancient China", Shanghai, 1922.

1 Asia and the dispersal of primates. Bull. Geol. Soc., China. Vol. 4, No. 2, 1925. pp. 133-183.

such discussion it will be well to present a brief review of the theoretical considerations which have suggested the preparation of these maps.

REVIEW

In 1876 Lord Kelvin, then Sir William Thompson, noted that if the earth were a viscous body its axis of maximum inertia and axis of rotation in ancient times might have been very far from their present geographical position.[2] Subsequently, however, he held that the apparent absence of tides in the body of the earth proved its essential rigidity, and that therefore no considerable displacement of its polar axis could occur.

In 1889 the great Italian astronomer, Giovani Virginio Schiaparelli, examined mathematically and in a more general manner the problem of polar displacement and fully set forth the results which would obtain (*1*) were the earth an absolutely rigid body; (*2*) were it composed of parts readily adapting themselves to the new form and distribution of stress; and (*3*) were the conditions intermediate between these two extremes.[3] In the first case he showed that at no time could the earth's polar axis have been shifted from its present position to an extent greater than a fraction of a degree. In the second it was proved that a very rapid shift in the position of the polar axis would obtain, which, had it occurred, could not fail to have been detected instrumentally and historically. In the third case it was shown that the earth would behave as a rigid body until the accumulation of stresses reached a certain limit at which point adjustment would occur and slow but extensive polar migration become possible.

Schiaparelli's important and illuminating investigation has recently been reviewed by Wright in his classic book on the Quaternary Ice Age,[4] since modern investigation has demonstrated the presence of small earth tides, and has thus focused attention once more on the question of polar migration and its influence on past climates.

In the opening decade of the present century numerous investigators became interested in the problem of polar drift. Among these may be mentioned in particular Reibisch[5] who in 1901 formulated his "Polar Pendulation

2 Report of Section of Mathematics and Physics, page 11 of British Association, 1876.

3 Schiaparelli, De la rotation de la terre sous l'influence des actions Geologiques. Petrograd, 1889.

4 Wright, W.B., The Quaternary Ice Age. 1914. London.

5 Reibisch, P., Ein Gestaltungs Princip der Erde. Jahresb. d. Ver. f. Erdkund., Dresden. 1901. Pp. 105-124.

Theory." and Kreichgauer[6] whose work on equatorial migration appeared in 1902.

Kreichgauer published evidence from a purely geological point of view which led him to conclude that the poles had migrated through an arc of 180° from Cambrian to the present time, the north polar track being through the Pacific basin from which it passed through Alaska to the Arctic basin in the early part of the Tertiary period. However, the greatest interest in this early work lies in Kreichgauer's plotting of the north polar track from the Tertiary onward, since his results offered a most plausible partial explanation for the extraordinarily varied climatic conditions of North America and Europe from that time to the present.

Reibisch, on the other hand, considered that his evidence indicated an oscillation of the poles back and forth along definite paths (meridians 10° E. and 170° W.). This Pendulation Theory was further elaborated by Simroth, who gathered a wealth of data both geological and biological to support his views, and published the whole in book form in 1907.[7] In this work it was emphasized that a very definite relation must obtain between polar pendulation and sea level. Following a polar shift, the earth would lag behind the ocean in adjusting its shape to the changed rotation axis so that the ocean level would tend to rise on land masses approaching the equator and fall on those approaching the poles. Marine transgressions would thus occur on opposite quarters of the globe in which land masses were approaching the equator, while regressions would characterize those opposite quarters which were approaching the poles. There would thus be two points on the equator termed oscillation poles (respectively on the west coasts of Ecuador and of Sumatra), each 90° from the oscillation path, at which no marine transgression or regression due to pendulation would occur. However, while throwing much light on the mechanism of world-wide marine transgression and regression in relation to polar shift, the Pendulation Theory could not provide an explanation as plausible as that of Kreichgauer for the extreme and varied glaciations known to have obtained in the northern latitudes in Post Tertiary time, since the north polar track it postulated was restricted to the neighborhood of one meridian.

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6 Kreichgauer, D., Die Aequatorfrage in der Geologie. 1902. Steyl.

7 Simroth, H., Die Pendulations-Theorie. 1907. Leipzig.

The most constructive and at the same time carefully documented and sustained arguments dealing with the question of polar wandering are without doubt those put forward by the late Professor Alfred Wegener* in 1922, in the third edition of his monumental book, "The Origin of Continents and Oceans," and in 1924 by the same author in collaboration with Dr. W. Köppen in the work entitled "Die Klimate der Geologischen Vorzeit." The latter book is essentially a development and elaboration of the palæoclimatic arguments presented in Wegener's earlier works on the Continental Drift Theory, but the data are presented in such a form that they may be used without reference to that theory.

In his introduction written for the English edition of Wegener's book, Dr. J. W. Evans aptly remarks: "Whatever may be the outcome of these observations and whatever modifications may prove to be required in the author's views on the evolution of the present configuration of land and sea, he has done most valuable service in directing attention to a new and important element in the transformations that the world has suffered, an element which no one will henceforth be able safely to ignore." Certainly the more closely I have studied the facts presented in this fascinating book and in its companion volume on past climates, the more difficult it has become not to recognize the very important bearing they have upon the study of primate dispersal, or for that matter of that of any other form of life terrestrial or marine.

Wegener's hypothesis of continental drift, while accepted in principle by not a few eminent authorities, has on the other hand encountered surprisingly uncompromising opposition from others. But regardless of this interesting division of present opinion on the subject, it may in truth be said that the very enunciation of the hypothesis in its present form represents a great contribution to research in many diverse fields.

Though certain of the concepts fundamental to Wegener's continental drift hypothesis yet remain unproven, there would seem to be but little room

* Early in May reports of Professor Wegener's tragic fate began to reach Peking. These, alas, have long since been confirmed, and the loss to science of this brilliant investigator is indeed a great one. It is most fortunate that his book on the theory of continental drift is available to English readers in the excellent translation of the third German edition under the sympathetic editorship of Dr. J. W. Evans. It is, however, greatly to be hoped that, as a companion volume, an English translation of the joint work of Köppen and Wegener on past climates may now be issued, since the latter work supplements with such a wealth of data, Wegener's earlier theoretical discussions.

for doubt that polar migrations of considerable magnitude have occurred in the past, and that their tracks as plotted by Köppen and Wegener for the Tertiary and Quaternary periods may be accepted as representing reasonable approximations of the actual paths then traversed. Such a theory of polar migration may obviously be accepted as a working hypothesis quite apart from that of continental drift. Shifting of the poles may have been brought about by a total movement of the earth's crust upon its more viscid interior, or it may be that its whole mass was involved in the movement, but it must be assumed that the inclination of the earth's axis to the plane of its orbit has not altered appreciably in geological time. The extreme climatic variations known to have obtained in North America and Europe during Tertiary and Quaternary time may thus be correlated in some degree with pronounced and progressive changes in surface latitude.

As noted above, the idea of polar migration as an explanation of Quaternary glaciation has been entertained by many investigators in the past, but though perhaps adequate to account for such extensive glaciations themselves, such a theory fails completely to explain the equally obvious fact that the glaciations were interrupted by successive interglacial periods during which relatively mild climatic conditions prevailed over previously and subsequently glaciated regions. To account for such extraordinarily varied climatic conditions, the influence of some additional factor competent to raise the mean annual temperature of the higher latitudes, and therefore indirectly of the earth's surface as a whole, must be assumed.

Of the various theories which have been proposed to account for the extensive and periodic climatic variations in the higher latitudes during Quaternary time, the astronomical hypothesis formulated by Croll in 1890 was the first to gain any wide acceptance. This theory, primarily based on variations in the eccentricity of the earth's orbit combined with the precession of the equinoxes, has been the subject of full discussion by Wright in his book on the Quaternary Ice Age[4]. It has been accepted in conjunction with polar shift as providing a reasonable explanation of the Quaternary glacial and interglacial history of Europe and North America, by Köppen and Wegener in their book on past climates.

In the latter work, Köppen's discussion of the climate of the Quaternary

4 Loc. cit. supra.

is based on new and very elaborate mathematical calculations by Milankovitch of the variations of solar radiation obtaining during this period, due to the precession of the equinoxes and the changes in the eccentricity of the earth's orbit. According to these calculations, the Würm glaciation of Europe terminated about 65,000 years ago, although a subsequent cold phase, occurring 20,000 years ago and termed the Post-Würmian or Baltic advance (Bühl advance of Soergel) is recognized, and Köppen appears to consider it as marking the true close of the Würm cycle.

Wright[4] has pointed out that an almost fatal objection to Croll's Theory lies in the fact that it placed the close of the ice age at about 80,000 years ago, while De Geer's observations on the laminated glacial clays of Sweden indicated the antiquity of the event to be of the order of about 9,000 years. This important discrepancy between theoretical and observational data only becomes reduced and not at all eliminated by Milankovitch's recalculations. But other and more serious objections have become evident in respect to the competency of the Crollian hypothesis to account for glacial and interglacial phenomena.

During the last few years, Dr. G. C. Simpson has published a series of studies on past climates, of the most fundamental importance in the field of palæoclimatology.[8 9 10 11 12] In these studies, Dr. Simpson has been led to adopt Wegener's hypothesis of continental drift and migration of the poles as being the explanation of the main Quaternary glaciations. On the other hand, he has shown that the slight variations in distribution of solar energy postulated by Croll are inadequate to explain the interglacial epochs. Further, he has presented meteorological evidence of the most convincing character in support of the conclusion that the latter were the result of two large oscillations of intensity of solar radiation (of an order perhaps as great as 40 percent) occurring during the Pleistocene.

8 Past Climates. Q.J. Roy. Meteorolog. Soc. Vol. 53, No. 223, July 1927, pp. 213-225. Subsequent discussion, pp. 225-232.

9 Past Climates. Alexander Pedler Lecture, 1929. Mem. and Proc. Manchester Lit. Phil. Soc. Vol. 74, Session 1929-30, pp. 34.

10 Id. Abridged. Nature Vol. 124, No. 3139, Dec. 28, 1929, pp. 988-991.

11 Discussion on Geological Climates. Proc. Roy. Soc. Lond. Ser. B. Vol. 106. Feb. 1930, pp. 299-317.

12 The Climate during the Pleistocene Period. Proc. Roy. Soc. Edinburgh, Vol. 50, Part 3, No. 21, Session 1929-30, pp. 262-296.

It will be of advantage here to review briefly Dr. Simpson's conclusions. It is clear that a zonal arrangement of climates must have characterized the earth during all periods of geological time, and that the mean temperature of the zones must always have decreased from the equator to the poles. The actual climate within a zone depends upon two factors: (1) the intensity of solar radiation, and (2) the distribution of land and water. There is ample evidence to show that no change in the distribution of the latter elements alone could have produced the large changes of climate shown in the geological record. The mean climate of any zone is thus determined primarily by the total amount of solar energy received annually by the earth, any increase of solar radiation leading to an increase of the mean temperature of all zones, and any decrease to the reverse effect.

With regard to the general circulation of the atmosphere (which itself maintains the oceanic circulation) it is dependent for its energy on the differences of temperature between the equatorial and polar regions; if this difference is great the general circulation is active, if small it becomes less active. Thus temperature differences induce general circulation, while the latter tends to eliminate temperature differences; and since the present zonal temperature differences have existed for a very long period, it follows that the atmosphere is at present in a steady state in which a balance has been struck between these two opposing forces.

The first effect of an increased solar radiation would be to raise the temperature of the whole earth, but more so at the equator than at the poles. The increased temperature would be accompanied by increased atmospheric circulation, increased evaporation, and increased water content of the atmosphere, which together would lead to great increase in cloud formation and in precipitation in all latitudes. The change in cloud amount would then to a large extend tend to balance the effect of the increased solar radiation, the only temperature changes being those necessary to maintain the increased amount of clouds.

In regions of the earth at present glaciated, a reduction of solar radiation would result first in a reduction of mean temperature of the zone, in turn followed by a reduction in precipitation, since the atmosphere would carry less moisture, and also since general atmospheric circulation would decrease. In consequence of reduced snowfall, the ice accumulations would then decrease, and if such conditions persisted long enough, large areas might even become free from snow.

If solar radiation were to become increased, the above effects would be reversed. The mean temperature of the zone would rise, precipitation in the form of snow increase and all glaciers would increase in thickness and extent. Such conditions would, however, only represent the initial effect of the increased solar radiation. As the latter progressed, a point would be reached where the increase in zonal temperature produced summer melting of the ice masses. From this point onward, melting would become more and more important until finally the summer melting would exceed the annual snowfall and glaciers would disappear.

Granted that two complete cycles of variations of solar radiation occurred in the Pleistocene, Dr. Simpson has thus shown on meteorological grounds that all the varied phenomena characterizing the Ice Age receive adequate explanation. He has summarized the several consequences of his theory by which its validity may be tested, as follows:

"(a) The four glacial ages occurred during periods of high temperature in all parts of the world.

(b) There are two kinds of interglacial periods:

  (1) warm interglacial periods which occur between the two members of each pair of glacial periods.

  (2) cold interglacial periods corresponding to the interval between the occurrence of pairs of glacial periods.

(c) Each pair of glacial periods, with the intervening warm interglacial period, coincides with a pluvial period in unglaciated regions."

Special Map Requirements

When discussing the subject of primate dispersal from the point of view of palæography in 1925,[1] I was quite unfamiliar with Wegener's book, of which I read the English edition for the first time in 1926. Though then reluctant to accept his drift hypothesis as anything more than a brilliantly suggestive and stimulating concept, I have since come to recognize the strength and ra-

1 Loc. cit. supra.

tionality of its appeal. Particularly is this evident in the light of Simpson's recent demonstration that only on some such hypothesis as that of Wegener could the Permian glaciations in what are now tropical and sub-tropical zones be explained.

However, with regard to the Tertiary and Quarternary distribution of land mammals, there would seem to be no such obvious and compelling reason to accept an hypothesis of continental drift, at least of a magnitude and scale such as Wegener postulated. On the other hand, the data presented by Köppen and Wegener and others in support of the theory of polar migration, here to be considered as distinct from continental drift, taken in conjunction with the equally weighty meteorological generalizations of Simpson, leave little room for doubt that wide variations from present latitude have obtained in different regions since Eocene time. As this in turn implies a redistribution of climatic zones and thus of possible migration routes, a reconsideration of some of the problems of primate dispersal is necessary.

Having accepted the theory of polar migration and adopted the polar trajectory plotted by Köppen and Wegener as being a reasonably close approximation to the true one, the first requisite for restudy of primate distribution and dispersal in the past is thus a new series of world maps on which data may be plotted with reasonable accuracy in their correct positions relative to each shift of the poles. The world maps accompanying Köppen and Wegener's text being quite inadequate for this purpose, the present series has been constructed.

In plotting the primary data of distribution, a world map on the Mercator projection has a great advantage over all others for several reasons. It has the invaluable property of being the only projection on which any bearing from any point may be laid off with accuracy and ease as a straight line. It has the further desirable qualities that it may be extended east and west as far as may be desired so the relative positions of points on opposite sides of the globe may be indicated, and also north and south so as to include the whole habitable area of the world.

There are, on the other hand, certain obvious limitations to the use of the Mercator projection in the study of distribution data. Aside from its excessive exaggeration of area in the higher latitudes, it is quite impossible to represent the polar regions on this projection and demonstrate on it the true relations to one another of the great land masses of the northern hemisphere. On this account it becomes necessary to supplement the Mercator chart with polar projections.

In the selection of supplementary geometrical azimuthal polar projections, there is a certain range of choice.[13] On a world scale, however, stereographic polar projections are of questionable value, in view of the great discrepancies in relative size and scale which they exhibit from centre to periphery. The Lambert azimuthal north polar projection, on the other hand, exhibits a peripheral distortion of opposite kind, and, in view of its property of equal-area, possesses some distinct advantages and has been used frequently in my laboratory for this type of work. However, for the purpose of present illustration world maps on a north polar azimuthal equidistant projection only have been used, the peripheral distortion in this case being intermediate in kind between that of the Lambert and stereographic projections.

METHODS USED IN MAP CONSTRUCTION

In the transference of distribution data from small, relatively large-scale maps to large small-scale Mercator charts, it was found that a 10° grid on the latter was a much more satisfactory one to work with than the usual 15° grid drawn on most Mercator projections. Since none of the latter then at my disposal were provided with proper marginal scales from which the desired 10° intervals of latitude could be determined, a Mercator grid having 10° intervals of latitude and longitude was drawn between latitudes 70° S. and 80° N. from the data tabulated in Deetz and Adams indispensable work. On this grid, reduced for convenience to a size accommodating the surface development of a three inch globe, all the Mercator projections illustrated here have been drawn, the drawings all having been made from the sixteen inch physical globe by Professor J. P. Goode of Chicago*. Since meridians are printed at 15° intervals on the latter globe, the necessary additional rulings were added to it.

While preparing the first series of Mercator projections in the different

13 See in this connection the invaluable treatise by C. H. Deetz and O. S. Adams, Elements of Map projection. U. S. Coast and Geodetic Survey. Special publication No. 68. 1921.

* Rand McNally Co., Chicago 1928.

polar positions, it became evident that in drawing at such a reduced scale on a 10° grid a considerable personal error factor was introduced which was difficult to measure. Accordingly, the modern Mercator map (*Figure 1*) was drawn last, under the same conditions as the others, in order that some estimate of the degree of this error could be made by comparison of it with more accurately drawn maps.

Figure 2 and all the other azimuthal equidistant north polar projections here illustrated, have been drawn also from the Goode sixteen inch physical globe, the grid for this projection having been drawn on a scale to accommodate the surface development of a five inch globe.

Since all available terrestrial atlas globes are mounted to permit only of movement about a fixed polar axis, and since their meridians and parallels of latitude are also oriented in a fixed manner about that axis, it became necessary to devise some means of overcoming these limitations before construction of any hypothetical projections could be undertaken.

To meet this difficulty a heavy stand was designed on which the Goode sixteen inch globe, stripped of its axial pivot rod, could be supported within a vertical circular protractor of metal, upon a shallow hemispherical brass cup of about three and one-half inch diameter. This cup was fixed to a vertical shaft rotating within accurately machined bearings in the plane of the protractor axis. Supported in this way, the globe could be adjusted so that any diameter could be made to correspond with its axis of rotation. A metal pointer was then made which could be introduced through a hole bored in the protractor ring exactly opposite the rotation center of the supporting cup. During orientation this pointer indicated precisely the position to which the desired point on the north polar trajectory should be adjusted and after this had been accomplished it served as an additional support to the globe during subsequent manipulations. Firm fixation of the globe to its supporting cup was obtained with the aid of plasticine.

After each successive orientation and fixation of the globe, a new reference grid of meridians and parallels of latitude had to be drawn, and for this purpose colored glass-marking wax pencils were used. On completion of each projection the lines so drawn were readily erased without injury to the surface of the globe. Of equal importance was the fact that these lines could be recorded with accuracy and distinguished from the permanent rulings of the globe in the series of photographs made of the latter after each projection had been completed.

It is important to note in a study of this nature that unless photographic records be made on which both the present and the theoretical meridians and parallels are evident together with map detail, it is difficult if not impossible subsequently to locate with any accuracy features not drawn at the time upon the theoretical projection. It has been noted above that with each alteration in the position of the polar axis all points on the surface of the globe, except two on the equator, must change their latitude. At only two points on the equator on opposite sides of the earth no change in latitude will occur, and these correspond to the so-called "oscillation poles" of Reibisch. These facts should be borne in mind when considering the maps accompanying this article. It may be added that orthochromatic films were used in making the photographic records of the present study, since these films were found to yield much greater map detail than those not red sensitive.

After orientation and fixation of the globe, the parallels of latitude were drawn in red at 10° intervals by means of the encircling protractor scale, the pencil being held at the successive desired intervals and the globe slowly rotated. With the aid of a 180° cardboard protractor, the equatorial plane thus defined was divided into thirty-six equal parts, beginning at a point fixed by the plane passing from the equator through Greenwich and the polar axis. From the points thus established the 10° meridian grid was then added in blue, and the globe was ready for study.

Discussion

*Notes on the various projections**

The north polar trajectory as described by Köppen and Wegener from the Eocene to the present is indicated diagramatically in *Figure 2*, while in *Figure 1* all of it that can be shown on a Mercator map has been drawn. Projections have been constructed (*Figures 3 to 16*) representing respectively the altered longitude and latitude conditions which would result at seven selected points on that path if the present continental relations remained otherwise undisturbed.

* In *Figures 1 to 16* the land masses of the world are represented in solid black against a white marine background. In the palæogeographic maps on the other hand (*Figures 17 to 26*) the reverse convention has been used as explained in the legend accompanying each of the latter figures.

It should be noted that the north polar trajectory indicated in *Figures 1 and 2* differs somewhat from that shown in Figure 36 of Kōppen and Wegener's book. The path plotted in the latter illustration from the Miocéne westward, appears to deviate from the positional data given in the text. The Miocene and Eocene north polar positions used in the present study are those given in the Table on page 154 of Kōppen and Wegener's work in which, however, no exact position is indicated for the Oligocene pole. I have accordingly arbitrarily placed the latter in Alaska midway between its Eocene and Miocene positions, although in Figure 36 of Kōppen and Wegener's text the polar trajectory is shown coming from the west across the peninsula of Tchuktchis before the Miocene. It would seem, however, from the map on page 155 of their text that no such westward deviation of this path need be implied.

Close of Würm Phase. (Baltic advance or Bühl stage; *Figures 3 and 4*) The position of the north pole at this stage has been taken as lying 5° west of the maximum eastern swing of Kōppen and Wegener's polar trajectory, i. e., in latitude 85° north, longitude 5° east, present reckoning.

The oscillation poles, or fixed points on the equator during this polar shift, lie approximately in present reckoning on longitudes 80° west and 100° east, respectively. The approximate position of the present north pole is indicated by a circle in *Figure 4*, and it is there evident that over the half of the northern hemisphere in front of the shifting pole and between the designated modern meridians, all latitudes have been increased in greater or less degree, while those on the opposite half of the hemisphere have been reduced correspondingly. It has been noted above that in the absence of compensatory alternations of land level, marine transgressions should occur during polar shift in those quarters of the globe approaching the equator, and conversely regressions in those approaching the poles. The period in question, therefore, would be one characterized by marine transgressions in regions bordering on the North Pacific basin.

There is a considerable body of evidence available in support of the conclusion that the east coast line of China has been undergoing a slow progressive submergence, probably as the result of warping movements since at least Middle Tertiary times.[14] In view of this it is of no little

14 v. et. Barbour, G. B., The Pliocene snd Post-Pliocene History of China. Proc. Third Pan-Pacific Congress, Tokyo. 1926. Art. 56, pp. 1780—1797. Bibliography.

interest to note in the present connection that Niinomy [15] has recorded the occurrence of raised marine terraces of apparently recent origin 40 meters above present sea level on the South Manchurian coast. On the coast of Hongkong, also, Dr. C. M. Heanley has observed the occurrence of raised marine terraces of recent origin about 5 meters above the present sea level in a number of localities.*

In the southern hemisphere the position of South America has been shifted eastward through an arc so that its meridianal axis now falls on longitude 60° west, while at the same time the latitude of Cape Horn has slightly increased. In high latitudes, even such slightly altered relations may possibly have constituted a factor of importance in the development of the late Pleistocene glaciation of Patagonia.

In view of the subsequent discussion of this feature, it is of interest to note here that the north coast of Asia at this stage, except at its extreme eastern end, lies in latitudes appreciably higher than at present, and higher also than at any previous stage of the Quaternary.

Würm Phase (*Figures 5 and 6*). The position of the north pole during the height of the Würm glaciation is given by Köppen and Wegener as latitude 75° north, longitude 45° west, present reckoning, in a location approximating the center of Greenland.

During the polar migration to this new position, the oscillation poles upon the equator likewise were displaced and came to lie in present reckoning approximately on longitudes 45° east (off the coast of East Africa) and 135° west (in the Pacific Ocean). Between these designated meridians north of the equator and in front of the advancing pole, all latitudes were increased, while on the other half of the northern hemisphere the reverse effect obtained. Thus conditions favouring marine regressions again characterized the North Atlantic region, and transgressions the coasts about the North Pacific basin.

In the southern hemisphere New Zealand, Tasmania and the southern part of Australia became shifted to quite high latitudes. This circumstance, in combination with the concomitant marine regressions which would attend such southern shift, would seem to be amply sufficient to account for a marked

15 Niinomy, K., Crustal movements in South Manchuria. 1927. Dairen. (v. et Barbour, (14) loc. cit. supra).

* Personal communication from Professor J. L. Shellshear of Hongkong.

development of mountain glaciation in these regions. On the other hand, practically the whole of the South American continent came to lie north of latitude 40° south, as a result of the changed position of the poles.

The whole of Eastern Asia became shifted to the south, and its longitudes, on account of rotational movement, also shifted to the west. The Philippines and Cambodia came to lie upon the equator, the gulf of Chihli just outside the tropics, and the major part of Japan proper wholly within the latter.

As a result of these widespread changes, the great areas of Europe then glaciated came to occupy positions markedly to the north and east of those in which they lie today. The changed relation of these areas with reference to Asia at this critical period would seem to be of peculiar significance, in view of the probable direct effect it had upon the climate of the great Mongolian region, and thus secondarily upon that of the whole of continental Asia.

On the probable age of the Malan Loess. On the basis of Simpson's hypothesis the Würm glaciation was initiated at the close of a period of increased solar radiation (characterized by greatly increased precipitation and increased temperature) and reached its maximum in the early stages of a subsequent period of decreased solar radiation (with greatly lowered temperature and decreased precipitation).

At the time of the onset of this cold period the continental region of the present Mongolian plateau lay about 15° south of its present latitude and was then presumably well watered. Progressive decrease in precipitation and lowering of mean temperature in this region followed, while its latitude throughout the maximum of the cold period remained but little altered. At the same time there must have developed, with the extension of European glaciation, a great area of relatively constant high pressure to the northwest of the Mongolian region, from which there issued prevailing cold and dry winds of high velocity. Thus conditions in the Mongolian continental region at this time were ideal to produce a rapid desiccation of its loosely consolidated and finely divided soil, there developed under circumstances which were particularly favourable for extensive rock-decay during Pliocene and early Quaternary time (*vide infra*). Once denuded of its binding vegetation, this soil would be progressively removed by wind action and transported southward to China, there to be deposited in regions sufficiently humid to support a permanent surface vegetation.

Barbour [16] has drawn particular attention to the fact that conditions very favourable to rock-decay must earlier have obtained in the continental Mongolian region, in order to provide the vast amount of loess subsequently removed from that area and distributed over regions to the south. He has supposed that pronounced regional Pleistocene uplift might account for the cold and arid conditions of the Malan physiographic stage during which were laid down the great loess deposits of China. If, however, the foregoing suggestion is correct, no agencies other than those already postulated to account for the Würm glaciation need be sought, and loess deposition in China would be contemporaneous with the Würm of Europe. Additional evidence in support of this concept will be adduced in discussing the next projection.

Pre-Günzian Phase (Figures 7 and 8). The position of the north pole at the beginning of the Quaternary is given in Köppen and Wegener's table as latitude 70° north, longitude 60° west, present reckoning. This point lies in Davis Strait about midway between the coasts of Baffin Island and Greenland. On the same latitude but 10° to the east, the polar position during the Günz glaciation is shown on the trajectory drawn in Figure 36 of Köppen and Wegener's book. In the same Figure the polar position during Mindel glaciation lies in longitude 45° west and *circa* 72° north, that of the Riss glaciation being also longitude 45° west and at *circa* 74° north. Thus during the whole period between the onset of Günz and maximum of Würm, the pole shifted through but 5° of longitude and 5° of latitude.

During polar migration from the Würm to the Pre-Günzian position the latitudes of all points along the east coast of Asia became further reduced, while those along the west coast of Europe greatly increased above their present values, the oscillation poles throughout this period being located as before in the Indian and Pacific Oceans, respectively.

In view of these facts it is of no little interest to note that a weight body of palæontological evidence has been accumulated by workers in the Orient pointing to the conclusion that throughout Quaternary time until its close, while Europe and North America were subjected to successive glaciations, the climate along the present east coast of Asia from Kamchatka to the tropics had been progressively warmer than at present. As far back as 1911, Yokoyama was forced to the conclusion from the evidence then at his disposal, that the

16 Barbour, G. B., The loess problem of China. Geolog. Mag. Vol. 67, No. 796, October, 1930. pp. 458-475. Bibliography. v. et. (14) loc. cit. supra.

temperature of central Japan had gradually increased since the early Pliocene to reach a maximum at the close of the Pleistocene, from which time to the present it had decreased.[17] On this account Yokoyama became convinced of the essential truth, viz. that of polar migration, which underlay the Pendulation Theory of Reibisch.

On the origin of loessic material. It is to be recalled from Simpson's generalizations that for a considerable time anterior to the onset of the Würm glaciation of Europe, there are strong reasons to suppose that the climate in all unglaciated regions of the globe was warmer and the precipitation greater than in the corresponding latitudes of today. Since the north coast of Asia during the warm Riss-Würm pluvial interval at no time rose above a mean latitude of 60° north, the whole of northeastern Asia must have had a warm-temperate climate. The Riss-Würm pluvial interval was in turn preceded by a long period during which colder and drier conditions prevailed than are found today in corresponding latitudes. Throughout this period, however, the mean latitude of the north coast of Asia lay more than 15° south of its present position, and almost 10° south of its position during the Riss-Würm interval, while Scandinavia and western Europe on the other hand lay in latitudes little below those they occupied during the Würm glaciation.

With the disappearance of the Mindel glaciation from lack of precipitation, there then occurred a period of world-wide lowering of temperature and humidity, but one characterized also by a pronounced reduction in general atmospheric circulation. If, therefore, despite its lowered latitude, the Mongolian region became extensively desiccated during this cool and arid period, there were lacking at the time prevailing winds of sufficiently high velocity to transport over long distances great volumes of the finer particles of its exposed and unconsolidated soil. Even the latter half of the cold Mindel-Riss interval, during which desiccation might be expected to have been greatest over the Mongolian continental area, would thus seem not to have provided the combination of circumstances necessary for the deposition of the Malan loess.

17. Yokoyama, M., Climatic changes in Japan since the Pliocene Epoch. Jour. Col. Sci., Tokyo Imp. Univ., Vol. 32, Art. 5, Oct. 1911, pp. 1-16.

The dry cold Mindel-Riss interglacial interval was in turn preceded by the first warm Günz-Mindel pluvial period of the Quaternary, during which the mean latitude of the north coast of Asia was further lowered and warm humid conditions must have obtained over the whole Mongolian continental region. It thus emerges from these further considerations of probable Quaternary climatic variations, that the optimum period for final desiccation of the Mongolian plateau occurred during the Würm glaciation of Europe with which, therefore, it has been suggested that the period of Malan loess deposition be correlated (*vide supra*).

Thus in the Mongolian continental region, a combination of low latitude and successive pluvial periods separated by one of desiccation, have provided those extraordinarily favourable conditions for rock-decay, to the necessity for which in this region, Barbour[16] earlier drew particular attention.

On correlation of oriental and occidental Quaternary deposits. During Quaternary times the peculiar and extreme climatic variations obtaining in North America and western Europe resulted in various and extensive glaciations in these areas, leaving behind them successive and characteristic deposits. On the other hand, during the same time period the climates of the northern latitudes of eastern Asia would seem for the most part to have been considerably milder than they are today. There would thus appear to be no *a priori* reason why the successive and characteristic Quaternary deposits of the west should have their exact counterparts in the east with which they may readily be correlated. It may be suggested however that if two complete cycles of variations of solar radiation occurred in the Quaternary as postulated by Simpson, the Polycene of Grabau probably extended from the close of the Pliocene to the close of the first Quaternary pluvial period. If this be so then the upper Sanmenian (Chou Kou Tien) deposits in which *Sinanthropus* remains have been recovered would approximately correspond in age to the close of the Günz-Mindel interglacial period of Europe.

Mid-Pliocene (Figures 9 and 10). According to Köppen and Wegener's trajectory the Mid-Pliocene north pole lay at a point in the interior of Melville Island in latitude 75° north, longitude 110° west, present reckoning. Since the beginning of Quaternary time the pole had thus shifted 5° to the north but had moved westward through 50° of longitude.

16 Loc. cit. supra.

This progressive movement of the pole to the west resulted in a rotation of the Eurasiatic land mass about its center. In consequence the latitudes of all points along the east coast of Asia were gradually raised, though by unequal amounts, above those they occupied at the beginning of Pliocene time (cf. *Figures 7 and 9*). Such progressive changes in latitude would harmonize well with Yokoyama's deductions as to the late Tertiary and Quaternary climates of central Japan, and also with what is known concerning past climatic conditions in North China.

Probable origin of red deposits. All areas of eastern Asia occupied latitudes markedly lower than today throughout the whole period that intervened between the Middle Pliocene and the time of onset of the Würm glaciation of Europe. This lowering of latitudes was a gradual process reaching its maximum at the beginning of the Quaternary, after which a general rise in latitude began. Thus, until Middle Quaternary times North China lay in latitudes comparable with those of Indo-China today where climatic conditions are such as to be highly favourable to rock-decay. It is therefore of interest to note that, of the wide-spread deposits of Pliocene age in North China, the so-called "red Hipparion clays" form a conspicuous element, resembling in texture and color many of the deposits loosely termed "laterites" [18] [19] which are so characteristically developed in southern Asia today; while lying upon these Pliocene soils, the so-called "reddish earths" of the Lower Quaternary occur.

Mid-Miocene (Figures 11 and 12). The position of the Miocene north pole is given in Köppen and Wegener's table as latitude 75° north, longitude 150° west, present reckoning. But one position for the Miocene pole is given by these authors, and the stage has been termed here Mid-Miocene only because the palæogeographic conditions of the Middle Miocene according to Grabau are later illustrated on this projection. (v. *Figures 19 and 20*) From Mid-Pliocene to Miocene times the north polar drift was straight westward and extended over 40° of longitude.

The most striking effect of this polar movement evident in the Mercator projection, is in the rotations of North America and Eurasia. The northwestern half of the former continent and the northeastern part of Asia have thus been brought to occupy positions above latitude 70° north.

18 Scrivenor, J. B., Laterite. Malayan Agricult. Jour., Dec. 1929. 6 pp.

19 Scrivenor, J. B., The Geology of Malaya. 1931. London.

The latitudes of points along the east coast of Asia have, however, been affected by this movement in very unequal degree, the North China region coming to lie in latitudes approximately 5° higher than obtain today in the same area. Since, however, the great movements of uplift about the present Tibetan Plateau begun in the Lower Miocene were probably still incomplete, it is not improbable that the Mid-Miocene climate of North China did not differ very widely from that of today.

Oligocene (Figures 13 and 14). The exact position of the Oligocene north pole is not indicated on Köppen and Wegener's trajectory. For reasons noted above it has been located arbitrarily in Alaska, half-way between the Miocene and Eocene north polar positions. As thus located it lies in latitude 65° north, longitude 155° west, present reckoning. From Miocene to Oligocene times the movement of the pole thus extended south through 10° of latitude and westward through but 5° of longitude. The great changes in the relative directional positions of the continents, brought about through the predominantly southern shift of the pole, are strikingly evident in the projections figured and require no further comment here.

Eocene (Figures 15 and 16). The position of the Eocene north pole is given in Köppen and Wegener's table as latitude 45° north, longitude 160° west, present reckoning. Thus the southern trend of north polar drift, begun in the Miocene, dominated its migration to Eocene times and resulted finally in its complete removal from the Arctic to the Pacific basin. According to Köppen and Wegener, the pole remained approximately in its Eocene position over a very long period of time, only drifting almost directly eastward therefrom over but 20° of longitude in the long period from the beginning of the Eocene to the Cretaceous. For this reason, in preparing the Palæocene palæogeographic maps no change from the Eocene north polar position has been shown.

The changes in the relative directional positions of the continents resulting from the location of the north pole in the Pacific basin are extraordinarily great, as may be judged from the projections figured. The rearrangement of climatic zones which would result from such change are equally profound, but require no discussion here.

In the above connection, however, it may be pointed out that there has recently been discovered among the valuable material collected by Mr. C. Li from the red sandstone of southwest Honan, the tooth of a small lophodont Perissodactyle, which has been identified by Pere Teilhard de Chardin[20] as *Lophialetes* sp. indet. The great interest in this specimen centers around the fact that heretofore *Lophialetes* has only been known from the relatively abundant specimens of the genus, determined by Matthew and Granger, taken from the Upper Eocene Irdin Manha formation of the Central Gobi. Reference to *Figure 16* makes it evident that in Eocene times both Honan and the Central Gobi areas lay in the same low latitude along the tropic of Cancer.

*Palæogeographic Map Series**

The foregoing notes have been restricted largely to a consideration of the positional changes which would result from progressive polar shift had world geography remained in other respects as it is today. It is, however, well known that such has not been the case, and that profound changes from present day conditions have obtained in the past. It will therefore be of value to enlarge the scope of these projections by adding thereto the data assembled in Dr. Grabau's well known series of Tertiary palæogeographic maps,[21] slightly modified in conformity with the present views of their distinguished author. This has been done in the projections illustrated here in *Figures 17 to 26*, in the construction of which extensive use has been made of the series of palæogeographic globes prepared in 1925.[1]

Mid-Pliocene palæogeography. (*Figures 17 and 18*) In these projections Nippon Bay has been extended northward to a point corresponding to latitude 62° north, present reckoning, a modification to the necessity for which Dr. Grabau drew attention in 1927 in the legend describing his palæogeographic map of the Middle and Upper Pliocene in Asia.[22] Two other slight modifications of his earlier maps are here introduced: (1) the transitory Behring bridge is represented by oblique lines, and (2) Davis Strait is shown as a bay terminating on the north in the neighbourhood of Devon Island.

20 Teilhard de Chardin, P. On the occurrence of a Mongolian Eocene Perissodactyle in the red sandstone of Sichuan, S. W. Honan. Bull. Geol. Soc. China, Vol. 9, No. 4. 1930. pp. 331-332.

21 Grabau, A. W., A Text Book of Geology. 1921. New York.

1 Loc. cit. supra.

22 Grabau, A. W., A Summary of the Cenozoic and Psychozoic Deposits, with special reference to Asia. Bull. Geol. Soc. China, Vol. 6, 1927, pp. 151-264.

* See also footnote on page 117.

It should be noted in these projections that the north polar position is represented at latitude 75° north, longitude 110° west, present reckoning. This is the polar position in the Middle Pliocene, but the palæogeographic detail covers the whole of Middle and Upper Pliocene time. It is therefore, necessary to recall that the high latitude in which the Behring land-bridge is represented in these projections only obtained during the former period. In Upper Pliocene time the Behring land-bridge lay between latitudes 50° and 60° north in a position in which no severe climatic barrier would intrude to block the faunal exchange known then to have occurred betweon North America and Asia.

Mid-Miocene palæogeography. (*Figures 19 and 20*) Dr. Grabau has noted in the legend describing his 1927 palæogeographic map of the Lower and Middle Miocene in Asia that Nippon Bay should be extended across eastern Hokkaido to latitude 65° north, longitude 170° west. [22] This modification has been introduced in the present projections where Nippon Bay is shown extending to the equivalent of this position in modern reckoning. One further modification of his earlier maps is here introduced since Mr. J. B. Scrivenor has made it clear that no marine transgressions occurred in Malaya during Miocene time.* Accordingly the whole Malay peninsula is here included within the land mass of Cathaysia.

Though the palæogeographic conditions obtaining in the Lower and Middle Miocene only are represented on the projections, it is to be observed that the land bridge of Atlantica extended between the Arctic and Atlantic basins during the whole Miocene period. It is therefore of interest to note that in its lower, latitudes Greenland was isolated from America by a wide marine barrier, the northern limit of which at no time during the Miocene extended further southward than appears on the present maps. Thus, though the way was open to westward dispersal of Miocene primates from Europe to Greenland, effective marine and climatic barriers were interposed to prevent the westward extension of their range to America.

Oligocene palæogeography. (*Figures 21 and 22*) In his 1927 description of the Oligocene palæogeographic map of Asia,[22] Dr. Grabau noted that "the Russian sea should be extended south of Turgai to longitude 80° east

22 Loc. cit. supra.

* Personal communication. v. et. (19) loc. cit. supra.

and latitude 52° north. Nippon Bay should be extended between Japan and Korea to longitude 140° east, latitude 45° north, covering the border lands of southern Japan and eastern Korea, and reaching southwestern Hokkaido." These alterations have been incorporated in the present projections.

In these projections attention should be directed to the wide and tropical Indo-Iranian bridge uniting present-day Central Asia (here southwestern Asia) with the northeastern part of Africa. It is from the southwestern corner of this broad land-bridge that the only Oligocene primate remains are known, these representing respectively the earliest catarrhine and the most primitive anthropoid forms yet discovered. The probable implications of these circumstances have been discussed elsewhere[1] but a new significance to those earlier observations is lent by the peculiarly interesting rearrangement of latitudes in this region, so evident in these projections.

Eocene palæogeography. (*Figures 23 and 24*). In his 1927 description of the Eocene palæogeography of Asia,[22] Dr. Grabau has noted that "between latitudes 40° and 50° north the sea should expand eastward to longitude 80° east. In the east the Pacific should cover southern Korea, and extend along the west side of Japan to latitude 45° north=Nippon Bay." These alterations have been incorporated in the present projections, where the marine extensions referred to are shown in relations respectively equivalent to the modern positions called for.

The extraordinary way in which almost the whole land surface of the globe is brought within the north and south limits of the temperate zones by the location of the north pole in the Pacific basin is strikingly evident in these projections. It is equally evident that but slight continental shifts would be necessary to bring both Africa and Cascadia wholly within such limits and provide a temperate to tropical climate over the whole land surface of the world, such as many investigators have postulated for the Eocene.

The relative positions of the central Gobi and Honan areas, to which attention has earlier been directed, is here most obvious. It would thus be but natural for primitive Eocene tapirids[20] to extend their range east and

22 Loc. cit. supra

1 Loc. cit. supra.

20 Loc. cit. supra.

west along the tropics, and in such relation the central Gobi and China evidently stand in these projections.

Palæocene palæogeography. (Figures 25 and 26). The only change from his earlier palæogeographic maps of the Palæocene that Dr. Grabau has found necessary, is the minor one of deflecting to the eastward the trend of the northern end of the Eastern Mountains of Asia, instead of extending it across Angara.[22] This modification has been made on the present projections. The location of the north pole has been considered as remaining unchanged during both Eocene and Palæocene periods, for reasons already given.

But little comment is called for in connection with these maps, save to draw attention once more to the fact that a wide Palæocene distribution of an early lemuroid-tarsioid stock is readily to be accounted for by the prevalence of land bridges in favourable latitudes during this period.

Conclusion

It has become apparent in the foregoing discussion that considerable evidence is to be adduced in favour of accepting the theory of polar shift on the Köppen and Wegener trajectory, and the hypothesis of Simpson on the variation of solar radiation, as together providing an adequate explanation of the Tertiary and Quaternary climatic conditions in Asia, so far as these can be inferred from present data. Thus, the same set of hypothetical considerations as give adequate explanation of the extraordinarily varied Quaternary climatic conditions known to have obtained in North and South America, in Europe, Australia, Tasmania and New Zealand, would seem in turn to yield equally satisfactory explanation for the peculiarly different climatic conditions characterizing Asia during the same period.

It is further evident that an exploration of the possibilities of the theory of polar shift as applied to both zoological and geological problems has been greatly handicapped in the past by the tradition of the fixity of the poles. So far as I am aware there is no atlas globe on the market in which the polar axis is not fixed with reference to the latitude and longitude grid upon the globe, a circumstance which probably accounts for the fact that map projections, such as those illustrated here, have not long ago been made available.

It would be a very simple matter for a maker of globes to depart from tradition in this respect and design an effective protractor stand

22 Loc. cit. supra.

within which a standard ruled globe could be mounted so as to rotate freely with reference to the fixed protractor poles. A globe thus mounted, and provided with a transparent gore or open-mesh grid in 10° of latitude and longitude, fixed to the protractor axis, would enable any investigator to study at will the relations between the theoretical and actual positions of points upon its surface in any polar orientation. It is believed that the advent of such a globe on the market would constitute a very distinct contribution to research.

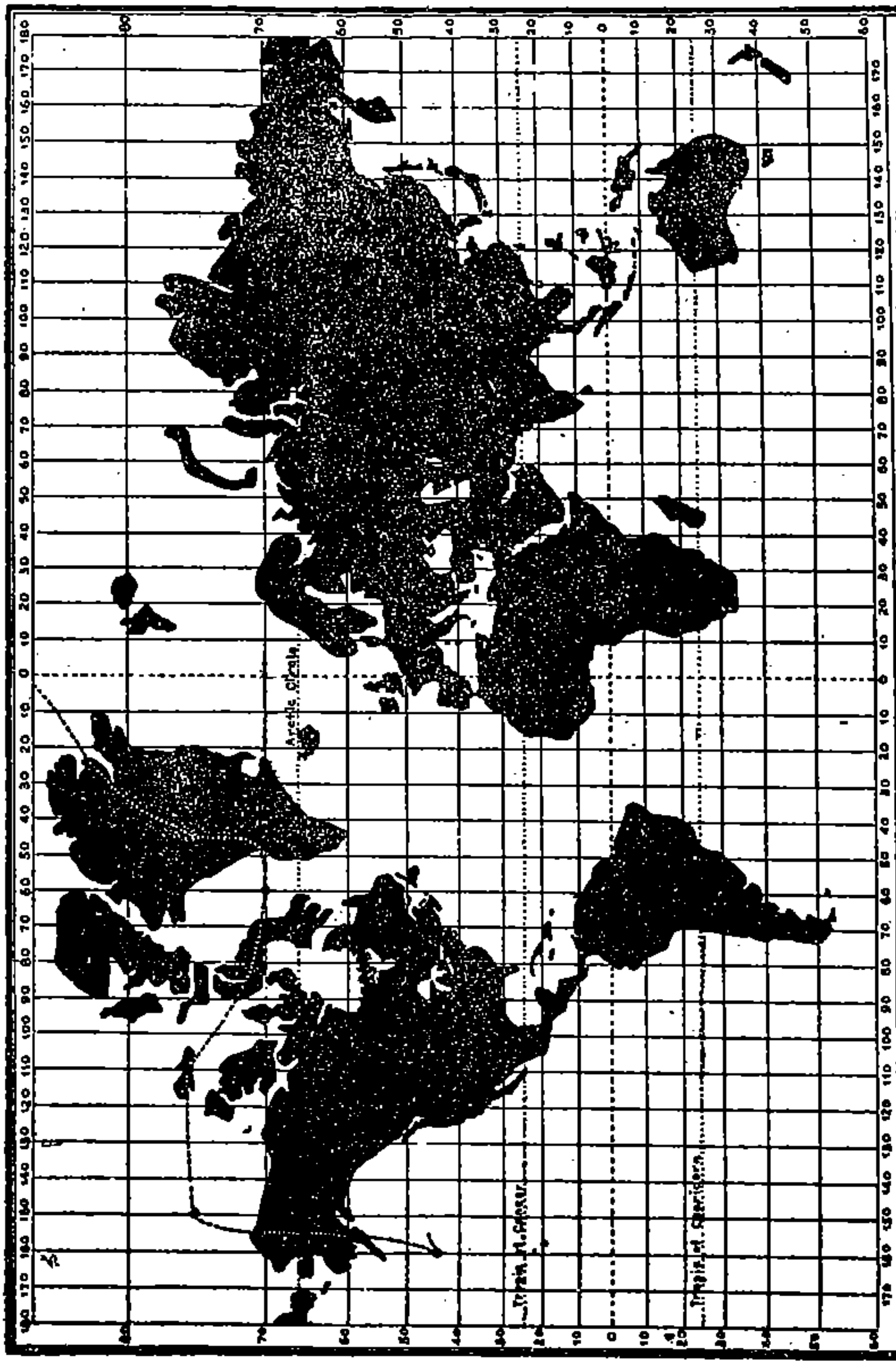
Throughout the present article Wegener's theory of continental drift has consistently been excluded from the argument with the single exception of a passing remark in referring to Eocene climate. It should be acknowledged, however, that it has become increasingly evident as this work progressed, that many problems of land fauna distribution require careful reconsideration in the light of Wegener's most stimulating concept. Indeed, in its broader aspects the latter does not appear necessarily to conflict in any irreconcilable way with the basic principles of distribution and dispersal enunciated in the late Dr. Matthew's classic treatise.[23] It is therefore planned at some future date to extend the present study to include a series of projections on similar grid and scale, on which may be plotted some of the geographical changes called for by the drift theory.

In conclusion it may be said that the polar shift and variation of solar radiation hypotheses in combination seem to display in their ability to give reasonable explanation for the extraordinarily varied Quaternary climates of the world, such goodness of theoretical fit that the onus now rests upon those who oppose these theories to provide others more adequate to serve as constructive working hypotheses. Certainly the whole question is one that cannot be dismissed by a simple refusal to meet the issue. It is largely in the hope that geologists in Asia particularly will give increasing attention to the questions raised, that I have had the temerity in this article to trespass in some degree upon the margin of their field of research.

23 Matthew, W. D., 1915. Climate and Evolution. Ann. N. Y. Acad. Sci., Vol. 24, pp. 171-318.

FIGURES 1 TO 26

NOTE: *In Figures 1 to 16* the land masses of the world are represented in solid black against a white marine background. In the palæogeographic maps on the other hand (*Figures 17 to 26*) the reverse convention has been used as explained in the legend accompanying each pair of the latter figures.



Mercator Projection — MODERN — 2·5 Inch globe. Track of Polar Drift according to data of Köppen and Wegener.

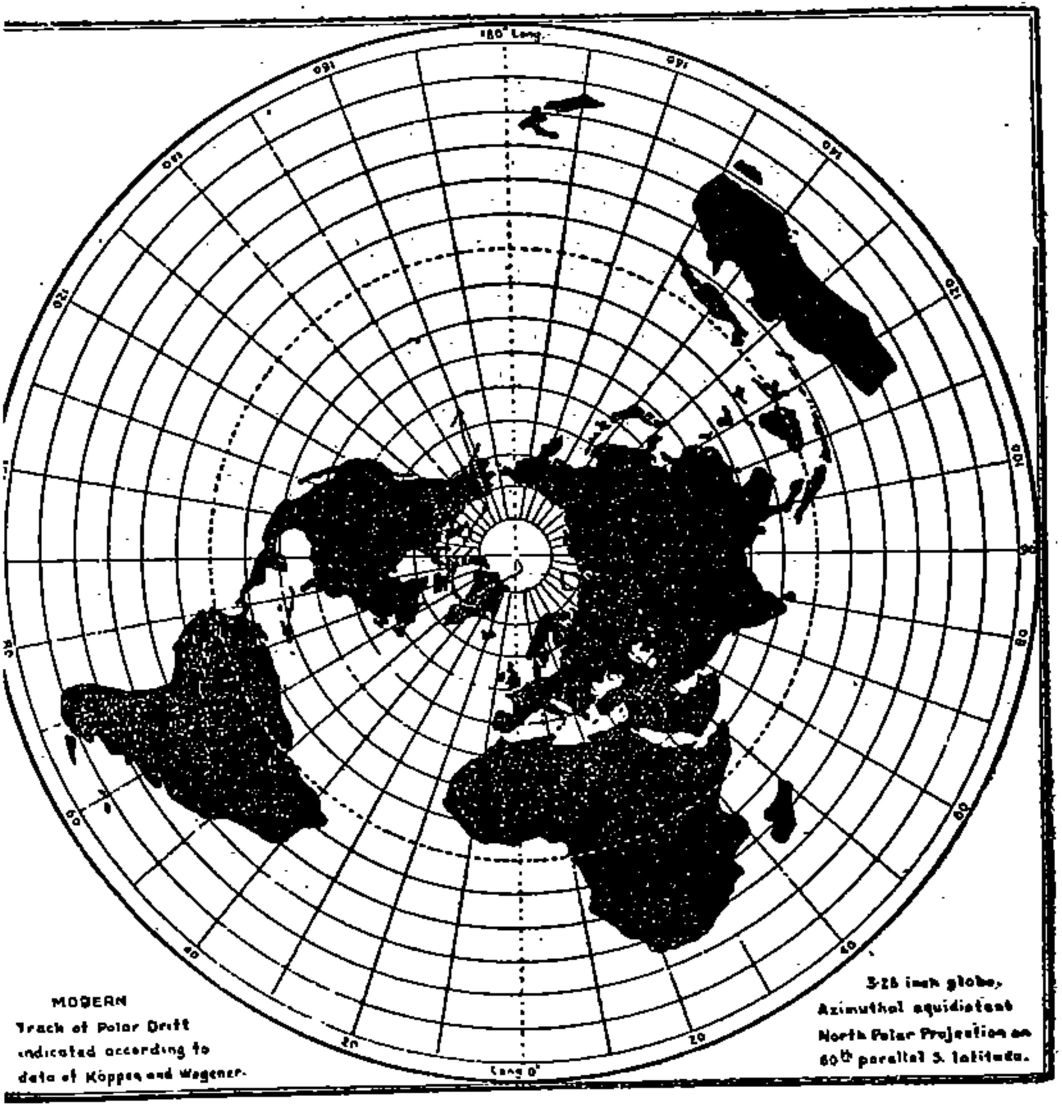
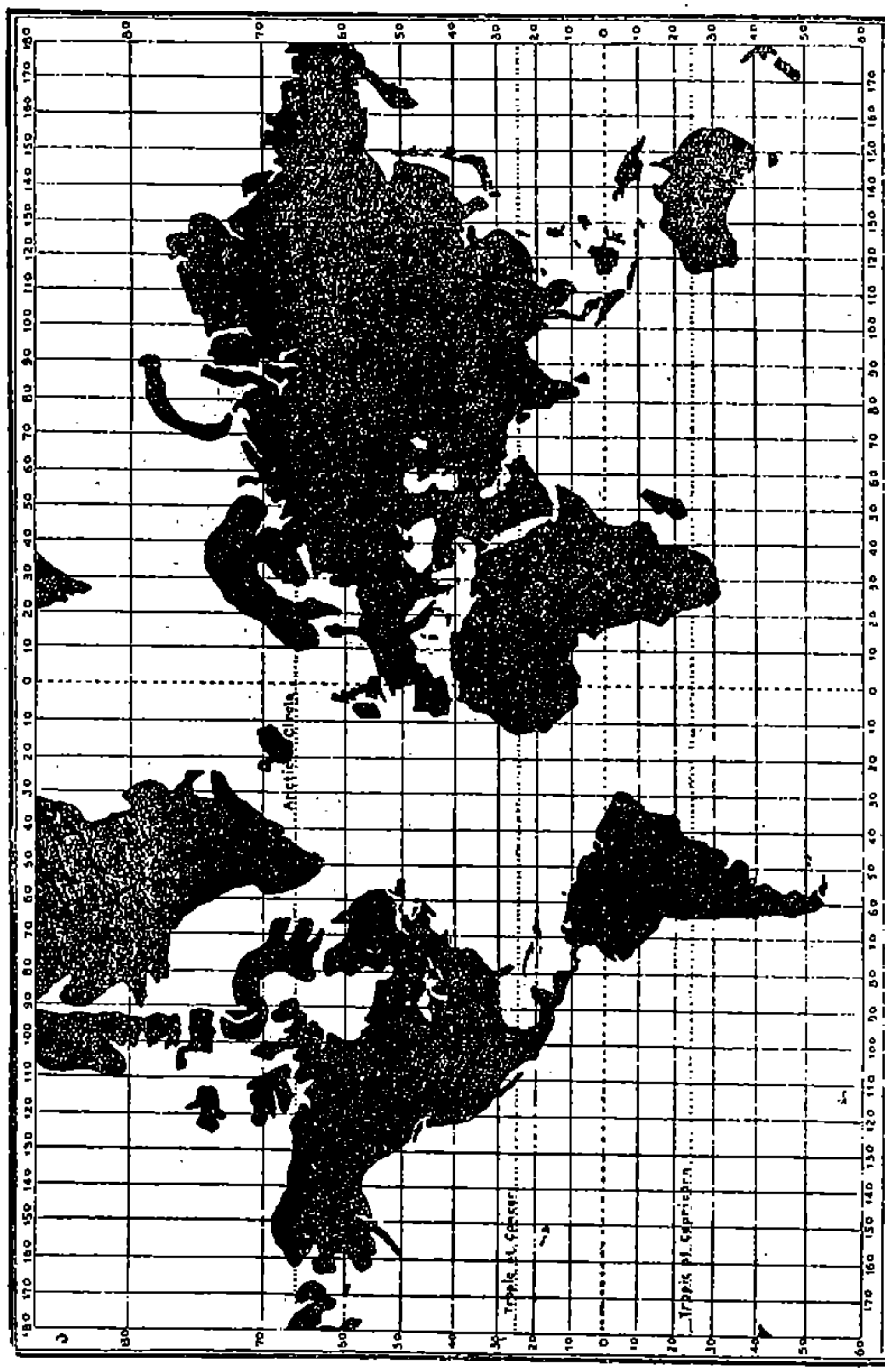

180° Long.
Long 0°
MODERN
Track of Polar Drift
indicated according to
data of Köppen and Wegener.
3.25 inch globe,
Azimuthal equidistant
North Polar Projection on
60th parallel S. latitude.

Figure 2



Mercator Projection. CLOSE OF [illegible] PHASE (Baltic advance) North Pole situated at point corresponding to present 05°N, 5°E

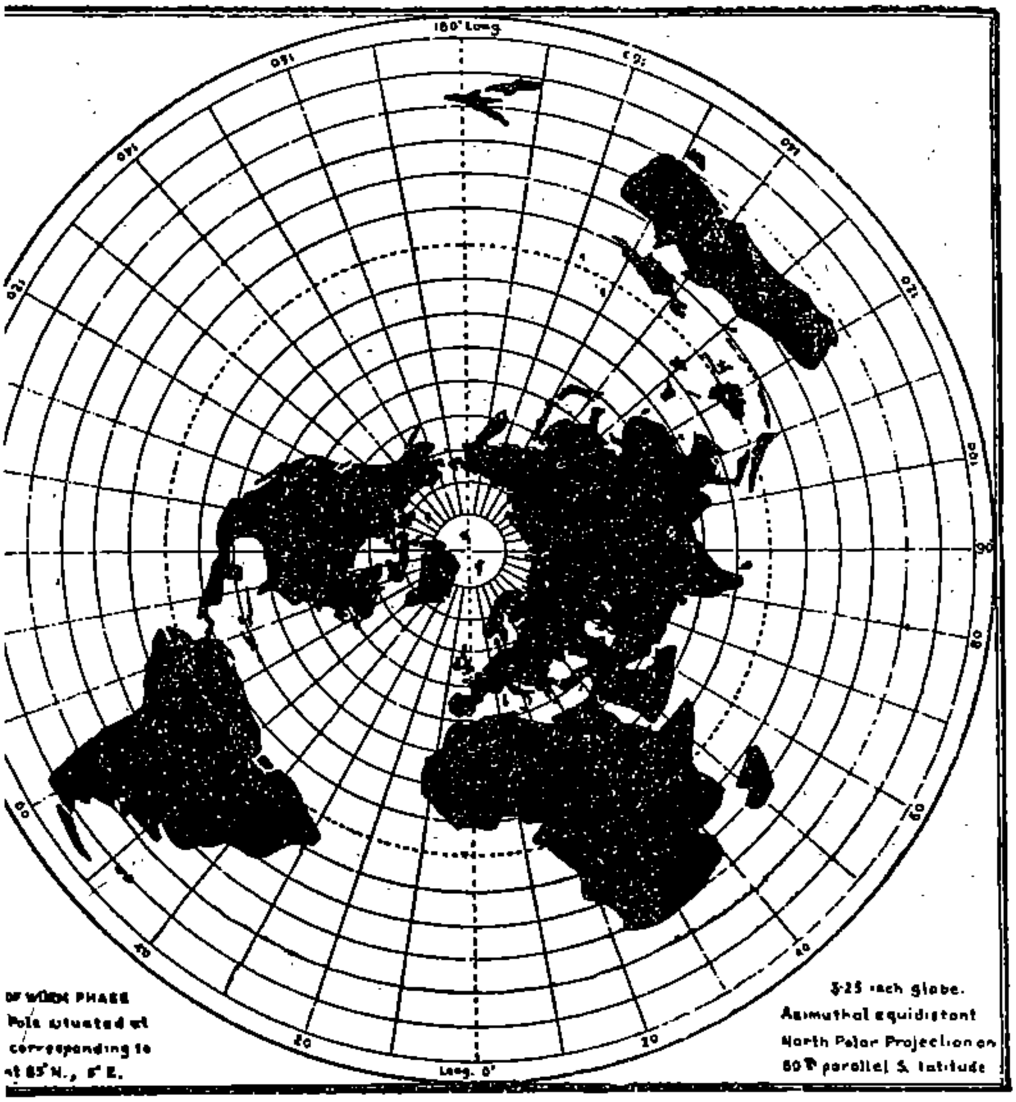
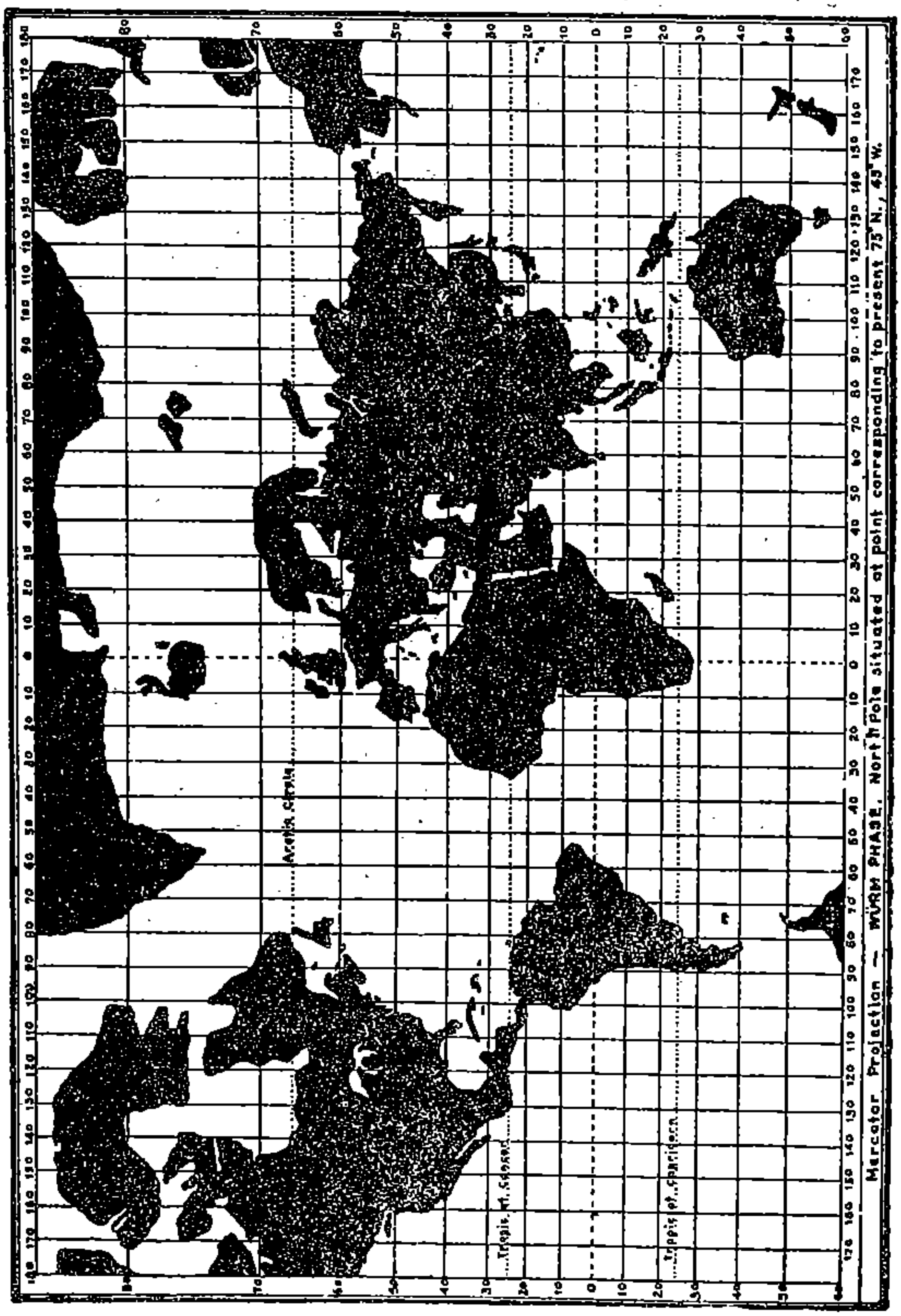

180° Long.
Long. 0°
OF WÜRM PHASE
Pole situated at
corresponding to
at 85°N., 5°E.
5·25 inch globe.
Azimuthal equidistant
North Polar Projection on
60° parallel S. latitude

Figure 4



Mercator Projection — WÜRM PHASE. North Pole situated at point corresponding to present 75° N., 45° W.

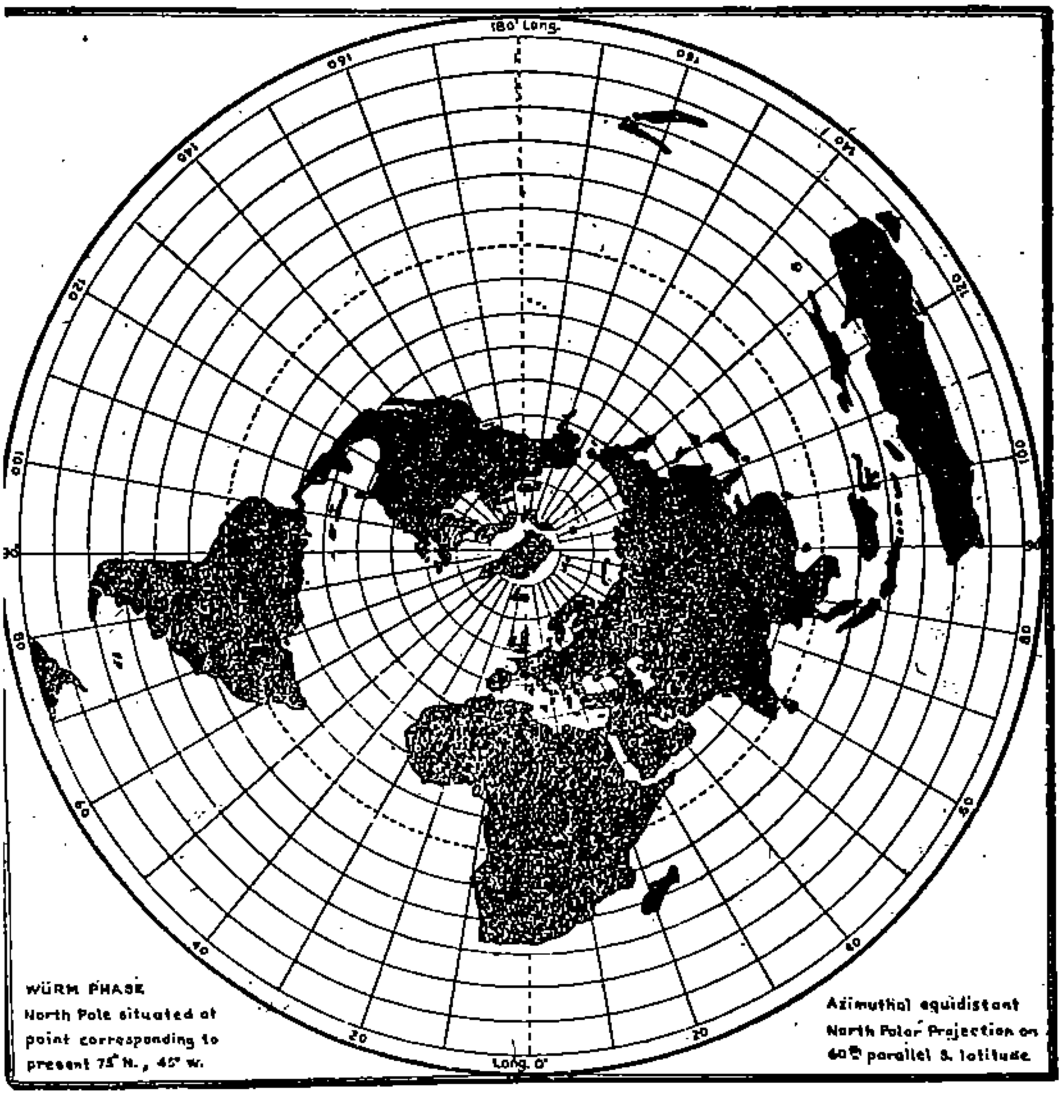
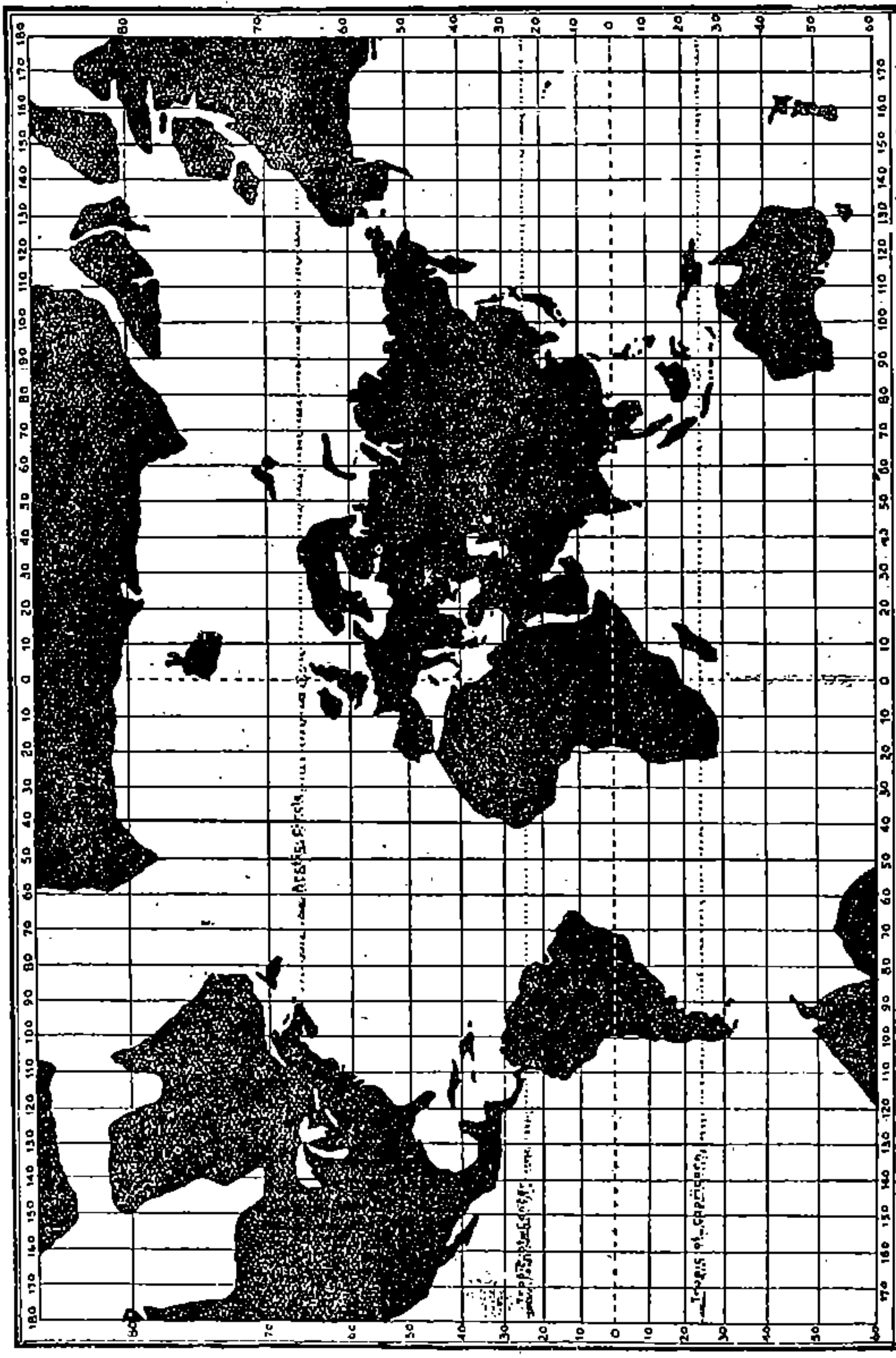

180° Long.
160
140
120
100
80
60
40
20
20
40
60
80
100
120
140
160
Long. 0°
WÜRM PHASE
North Pole situated at
point corresponding to
present 75° N., 45° W.
Azimuthal equidistant
North Polar Projection on
60th parallel S. latitude

Figure 6



Mercator Projection — PRE-GÜNZIAN PHASE. North Pole situated at point corresponding to present 70° N., 60° W.

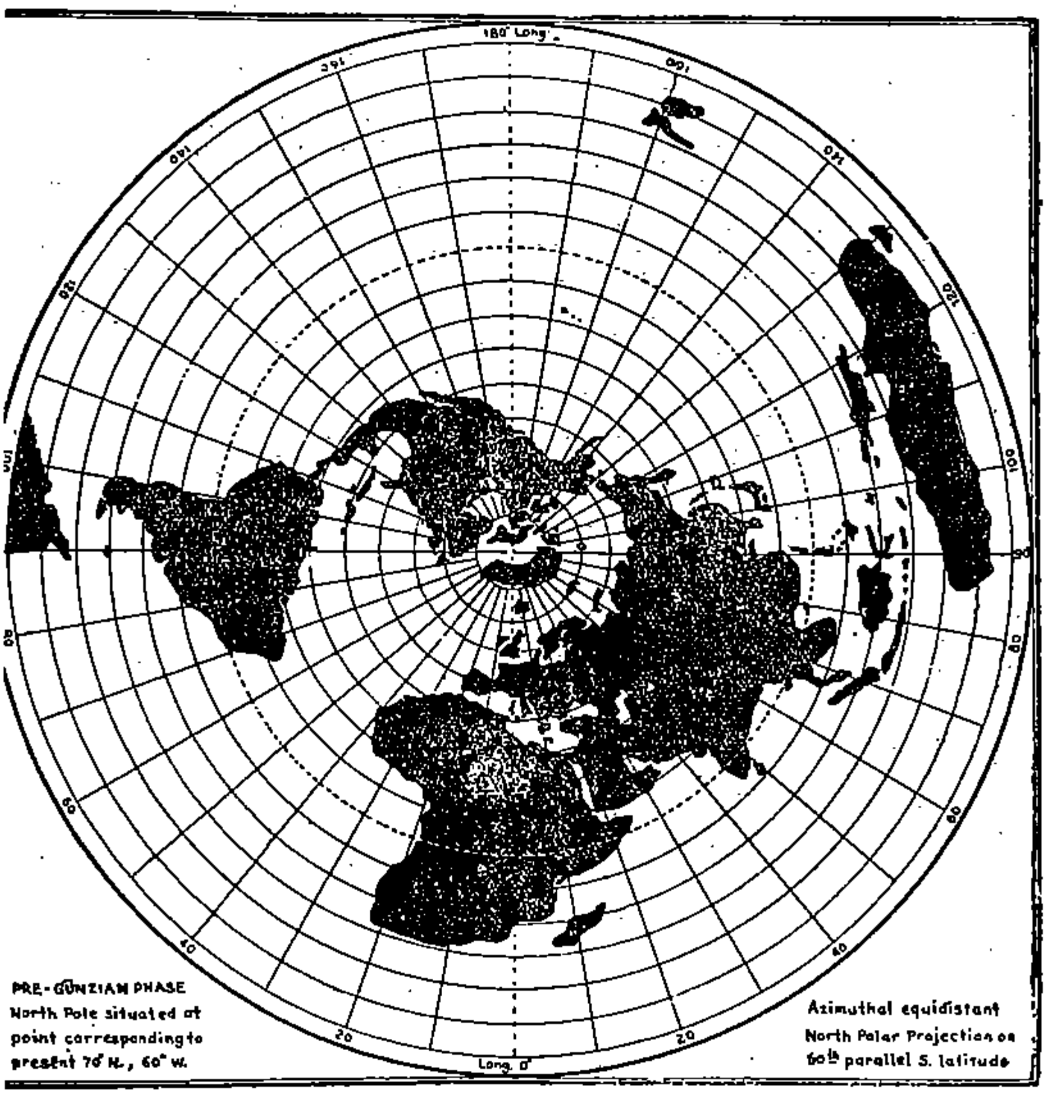
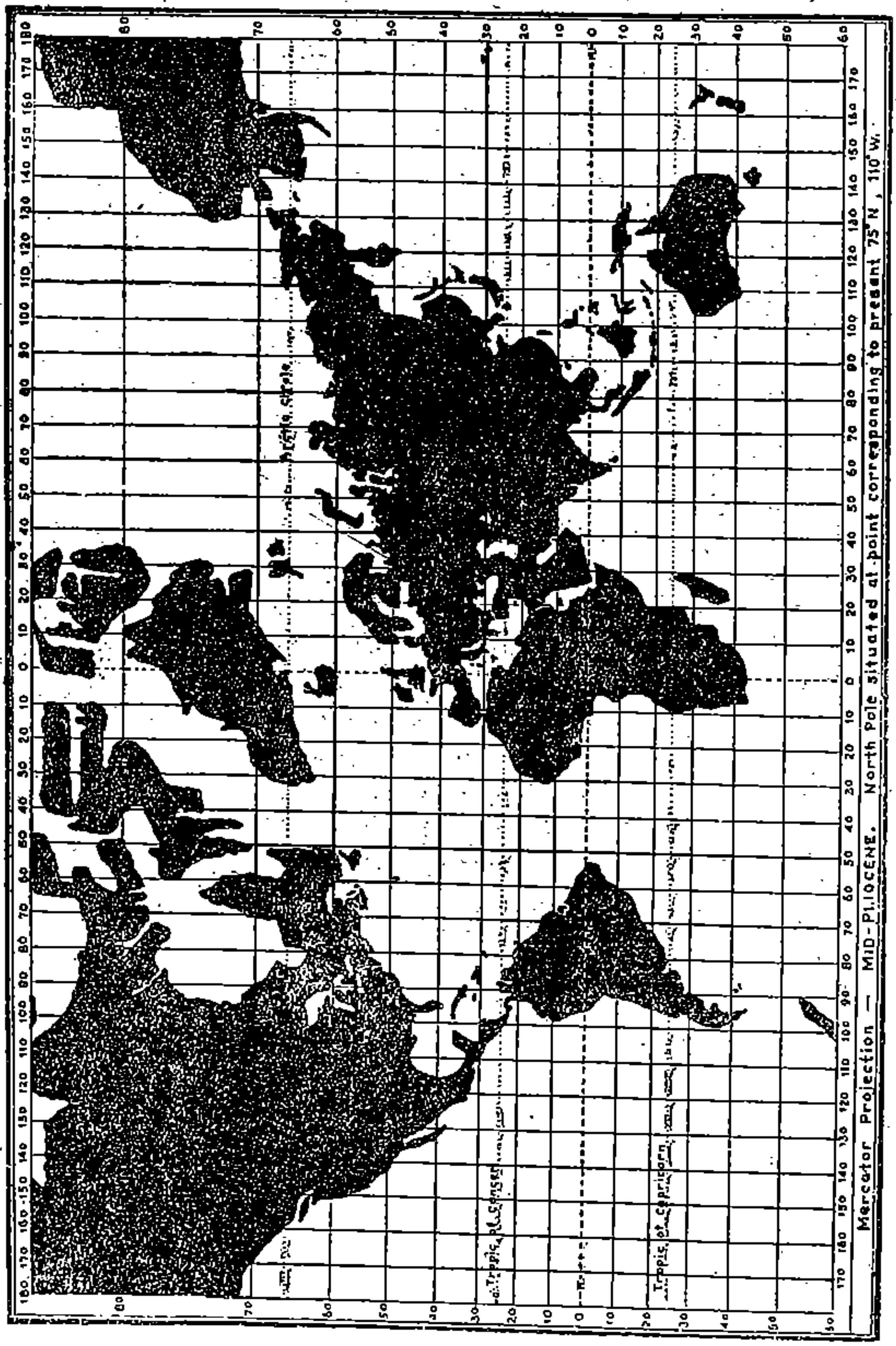

PRE-GÜNZIAN PHASE
North Pole situated at point corresponding to present 70° N., 60° W.
Azimuthal equidistant North Polar Projection on 60th parallel S. latitude
180° Long.
Long. 0°

Figure 8



Mercator Projection — MID-PLIOCENE. North Pole situated at point corresponding to present 75°N, 110°W.

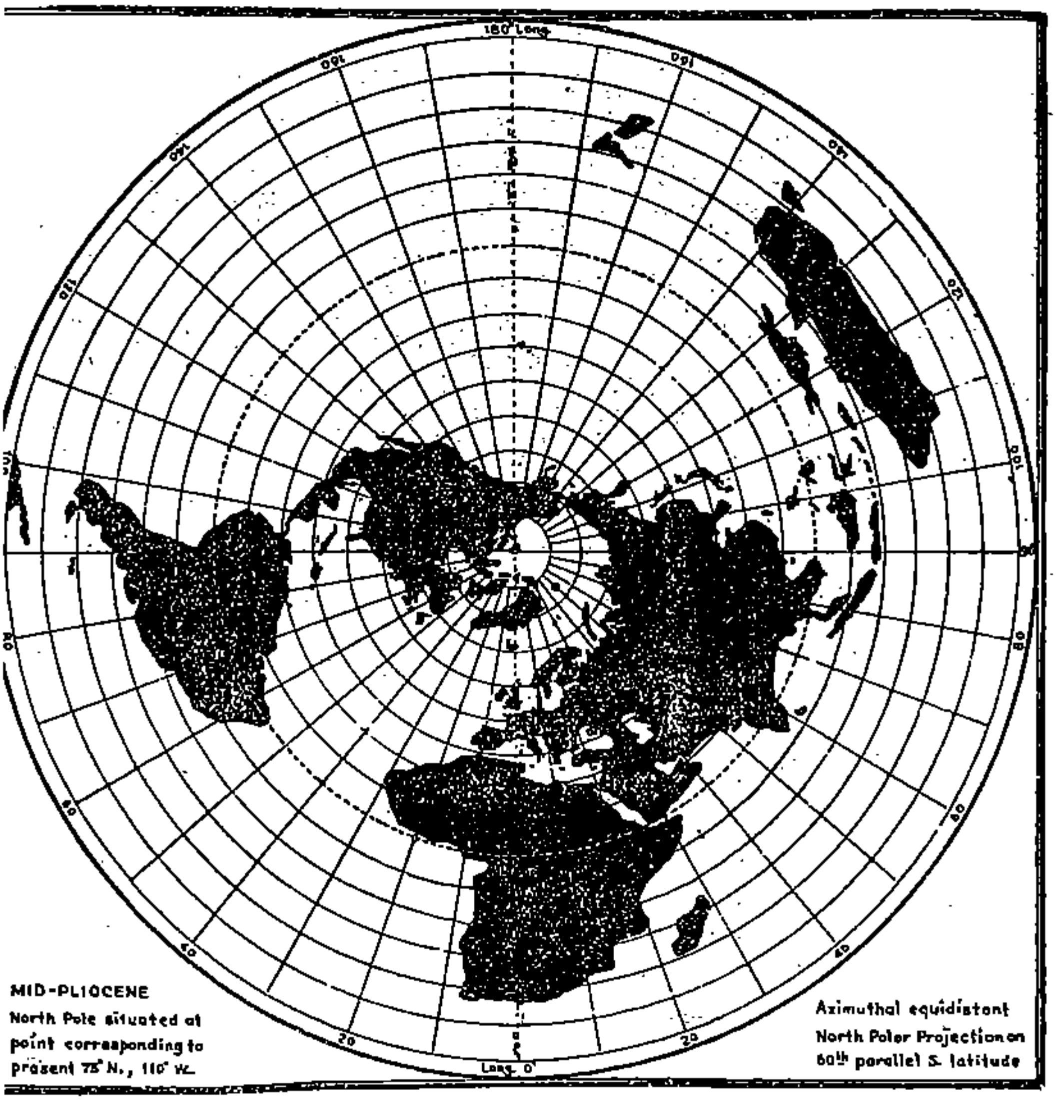
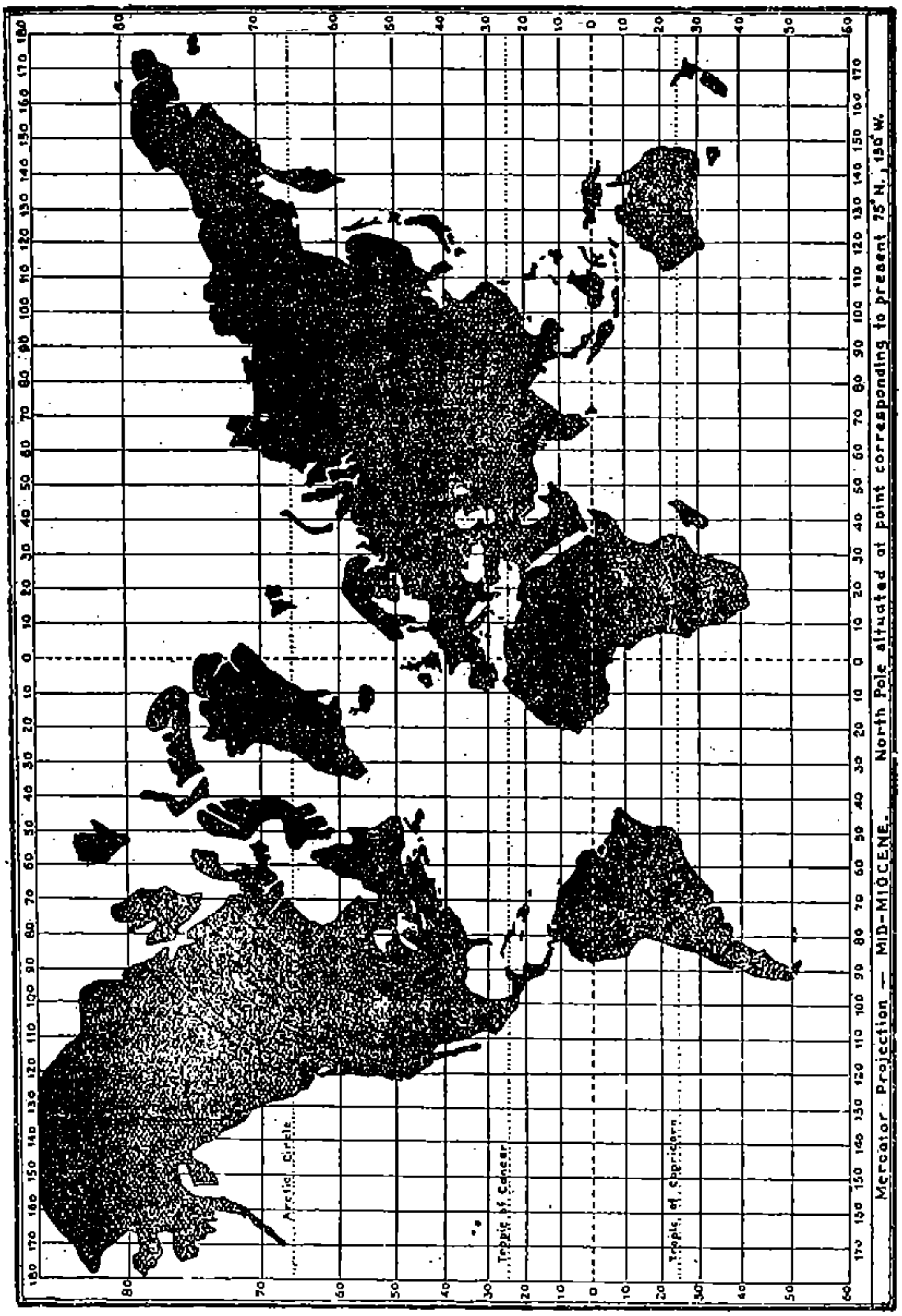

MID-PLIOCENE
North Pole situated at point corresponding to present 75° N., 110° W.
Azimuthal equidistant North Polar Projection on 60th parallel S. latitude
180° Long.
Long. 0°

Figure 10



Mercator Projection — MID-MIOCENE. North Pole situated at point corresponding to present 75° N., 150° W.

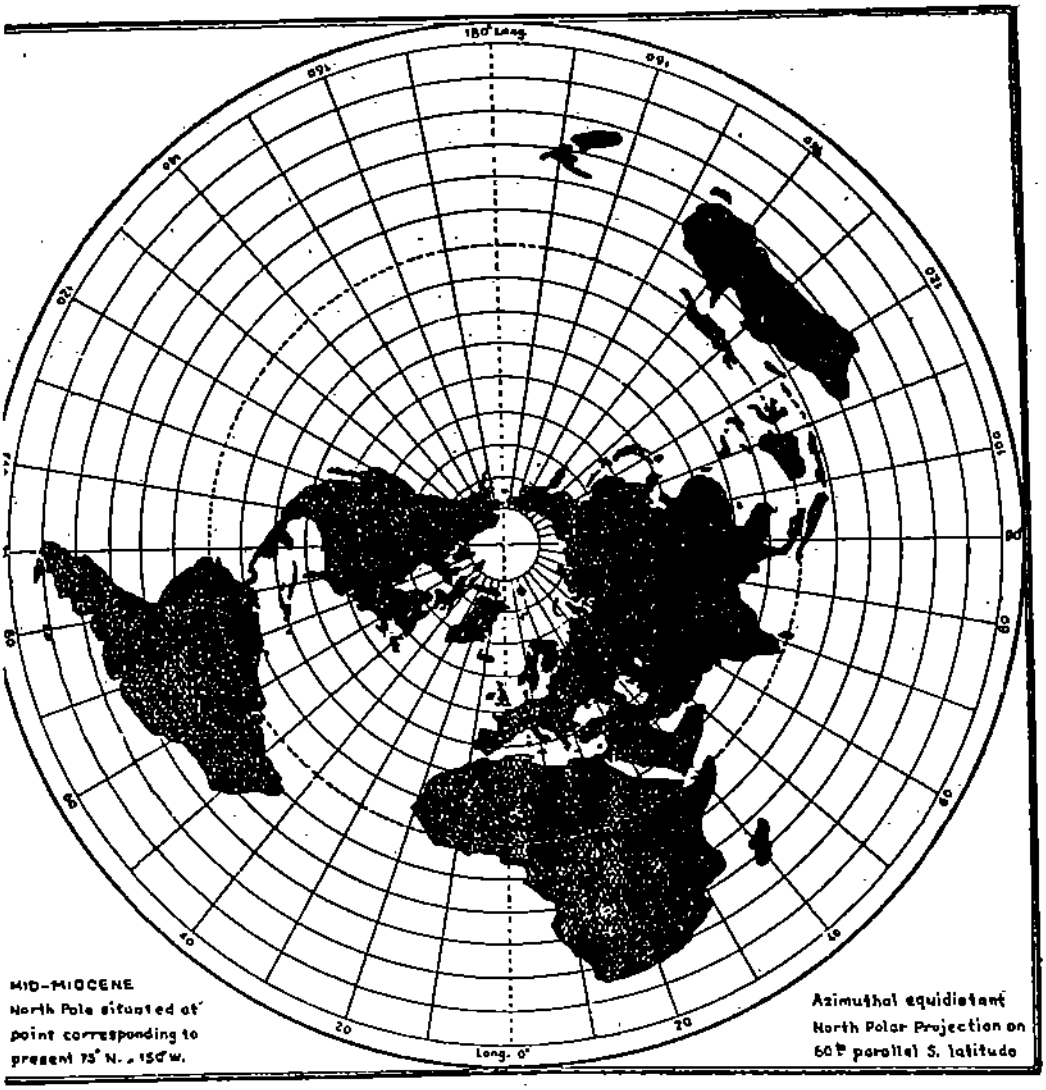
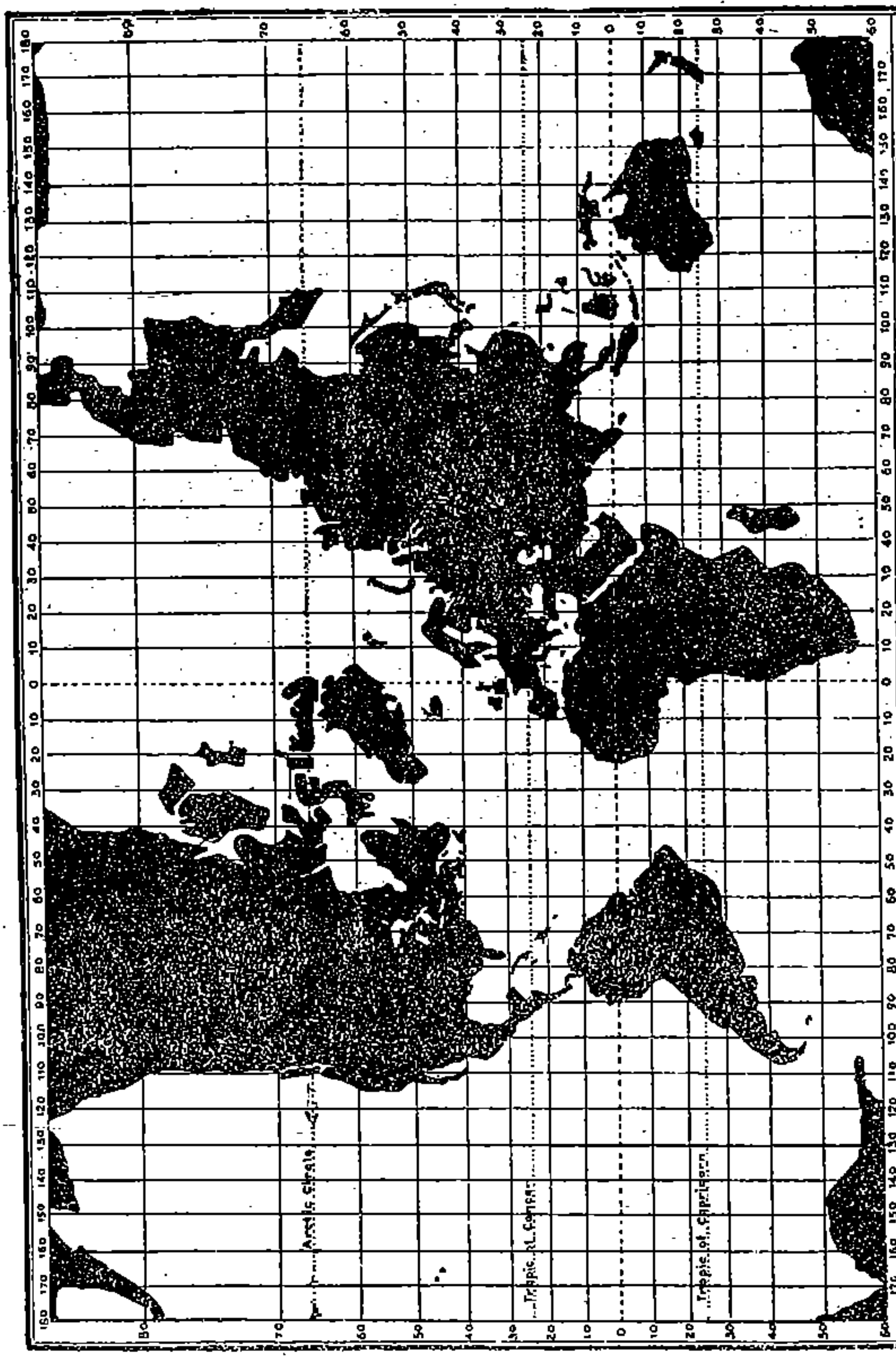

180° Long.
MID-MIOCENE
North Pole situated at point corresponding to present 75° N., 150° W.
Azimuthal equidistant North Polar Projection on 60th parallel S. latitude
Long. 0°

Figure 12



OLIGOCENE North Pole situated at point corresponding to present 65° N., 135° W.

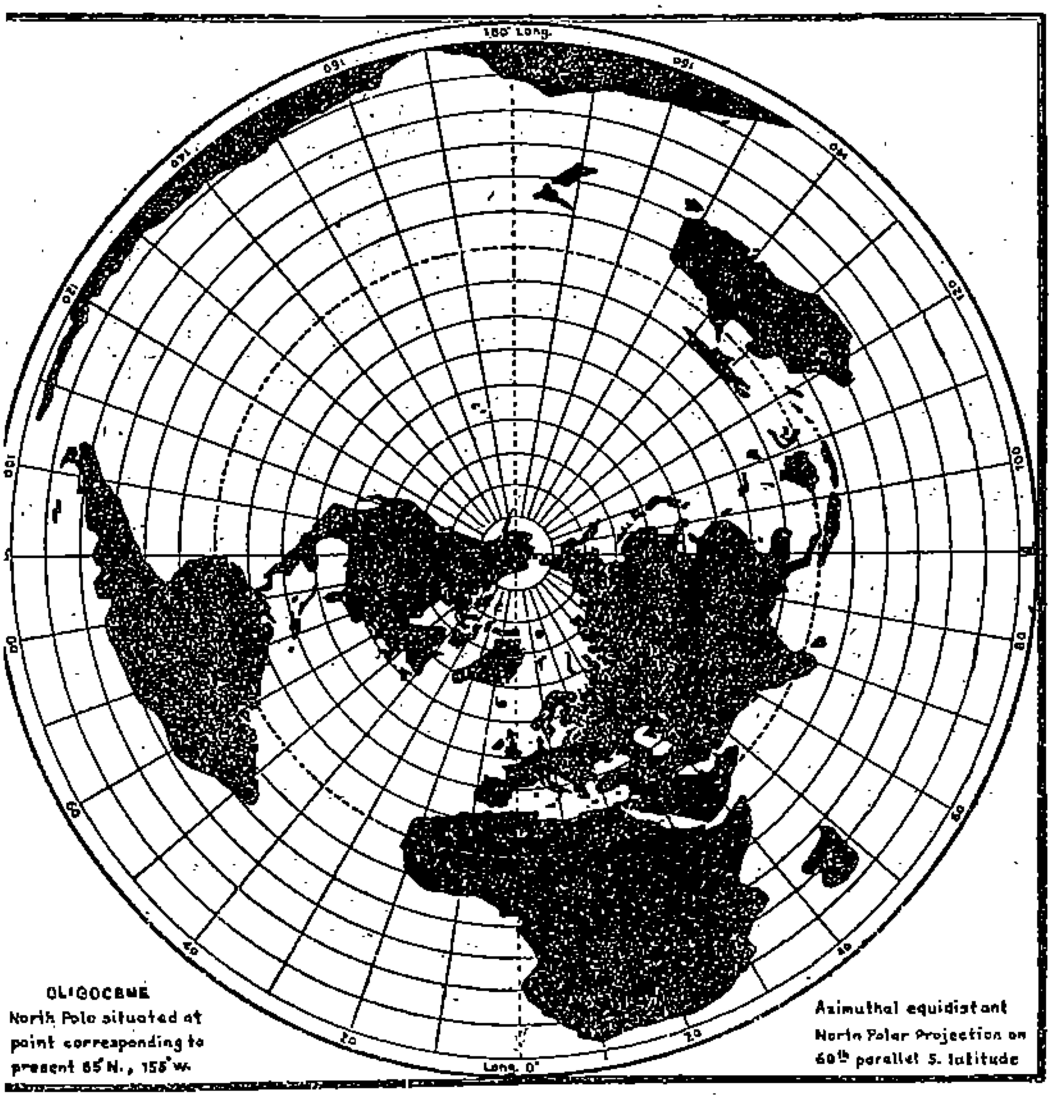
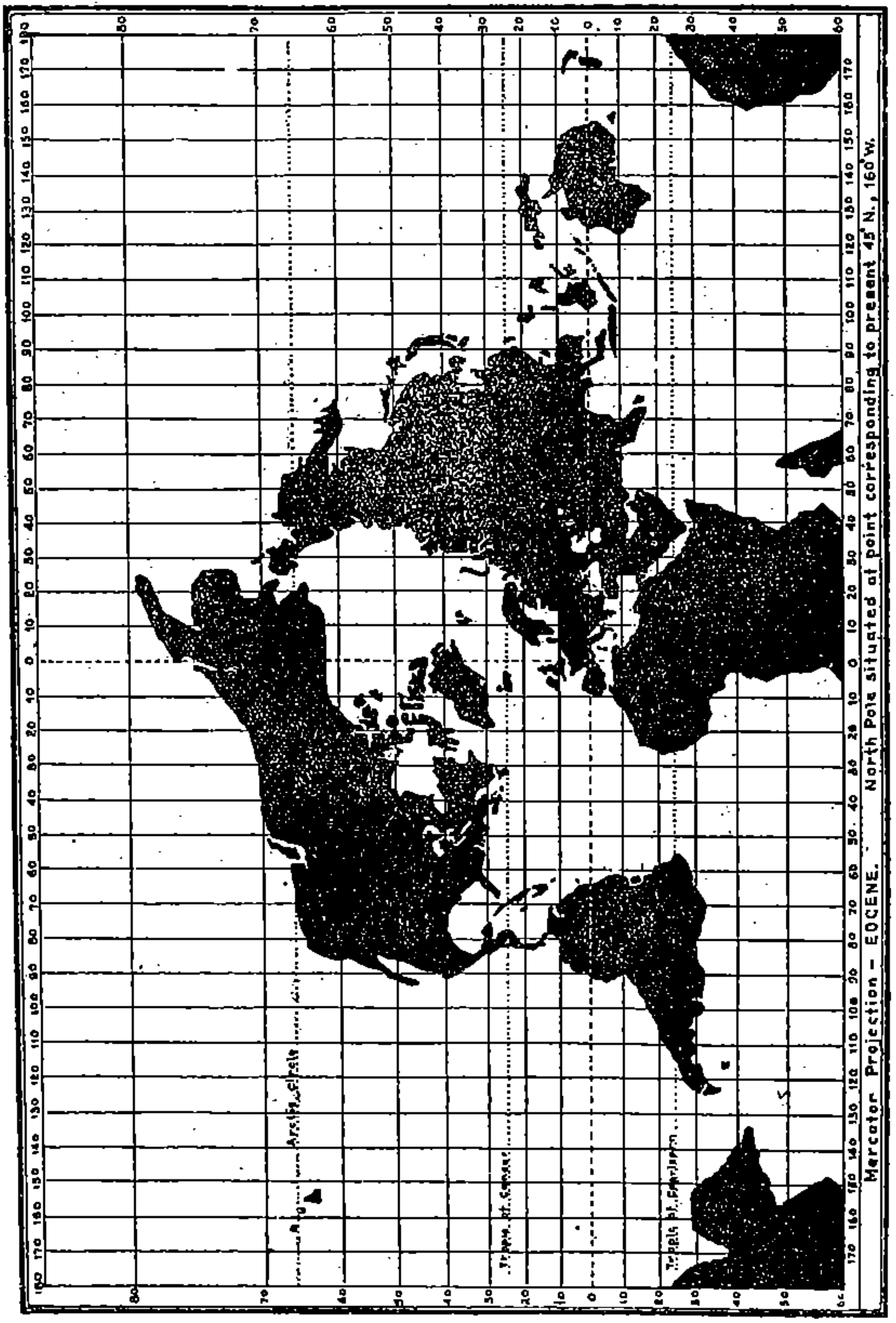

180° Long.
Long. 0°
OLIGOCENE
North Pole situated at point corresponding to present 65°N., 155°W.
Azimuthal equidistant North Polar Projection on 60th parallel S. latitude

Figure 14



Mercator Projection – EOCENE. North Pole situated at point corresponding to present 45° N., 160° W.

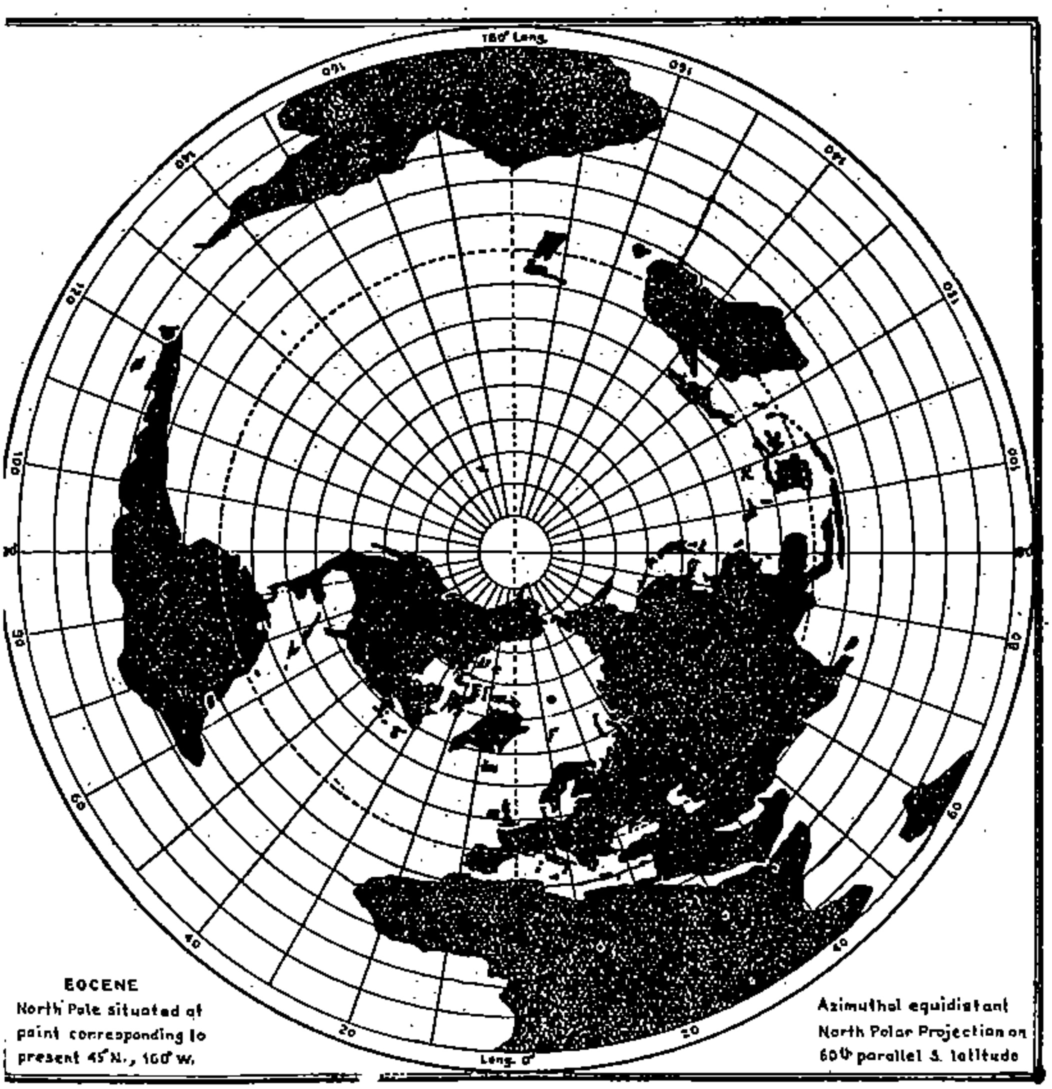
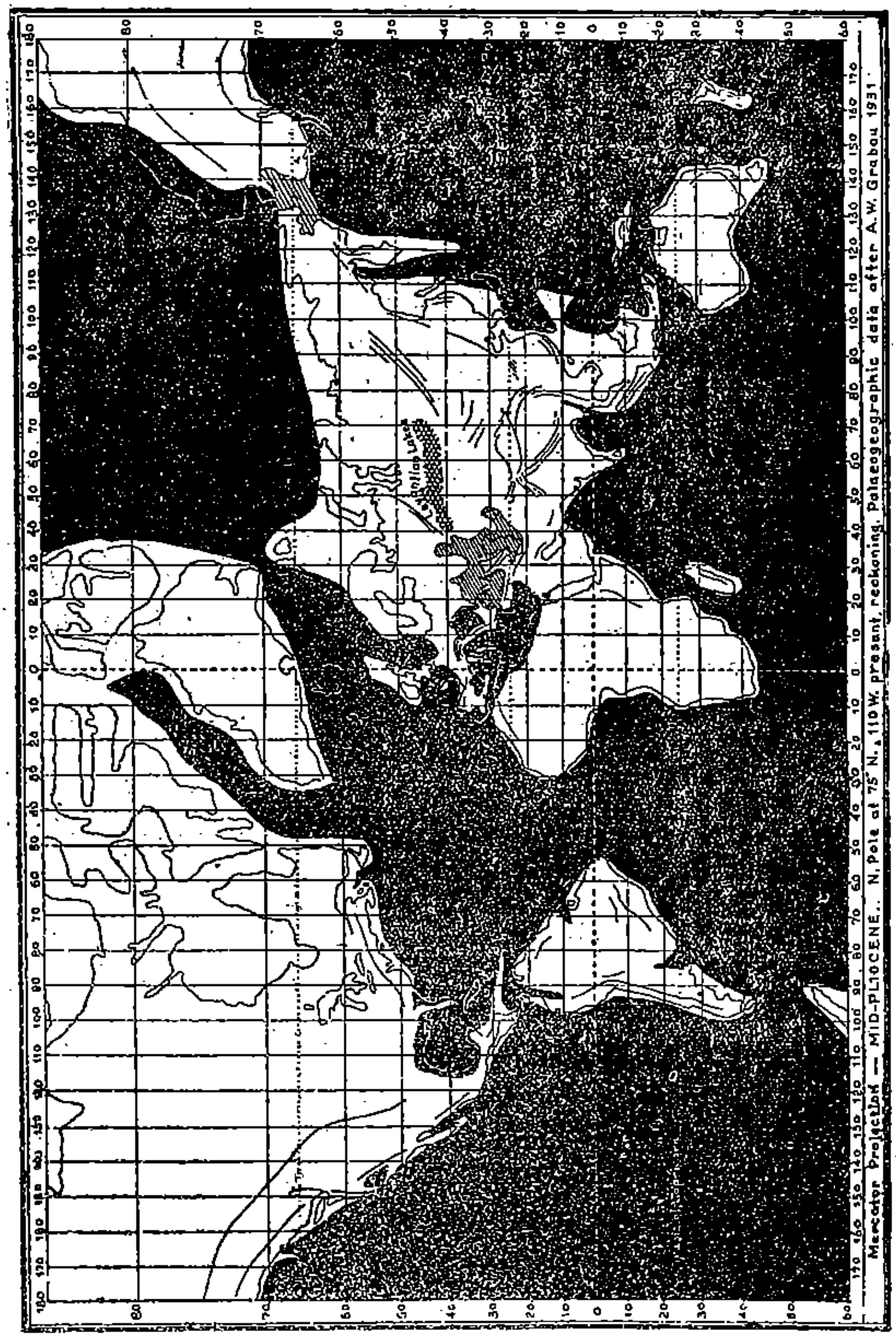

180° Long.
EOCENE
North Pole situated at point corresponding to present 45° N., 100° W.
Azimuthal equidistant North Polar Projection on 60th parallel S. latitude
Long. 0°

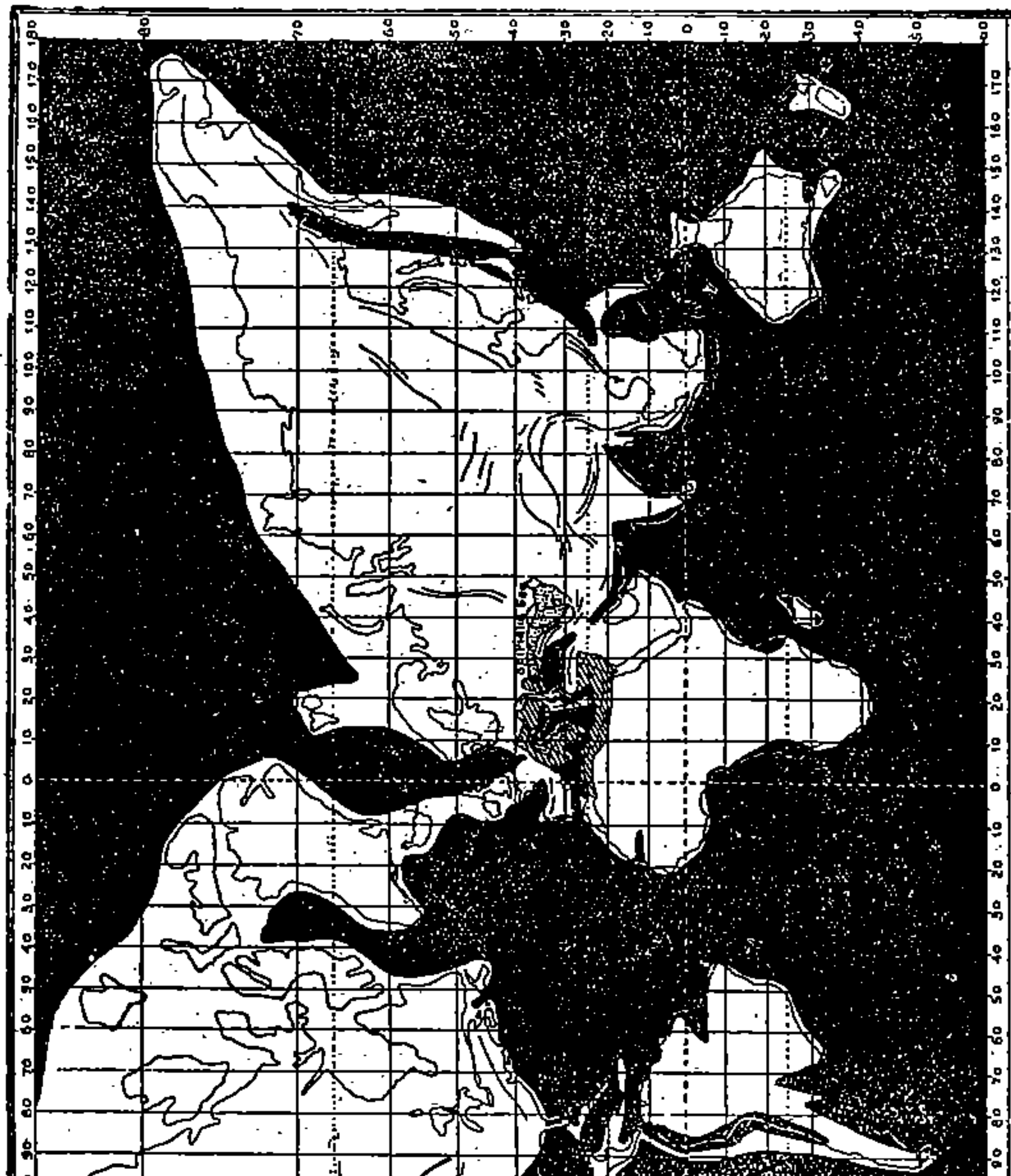
Figure 16



Mercator Projection — MID-PLIOCENE.. N. Pole at 75° N., 110 W. present reckoning. Palaeogeographic data after A. W. Grabau 1931

Figure 18

Explanation of conventions used in *Figures 17 and 18*: Pliocene land masses, white; marine transgresions not persisting throughout the stages represented, white with oblique line shading; great fresh-water lacustrine areas, cross-hatched on white (areas outlined in dashes only approximate); oceans and seas, black; trends of mountain systems, fine continuous black lines; outlines of present-day land masses as in *Figures 9 and 10*.

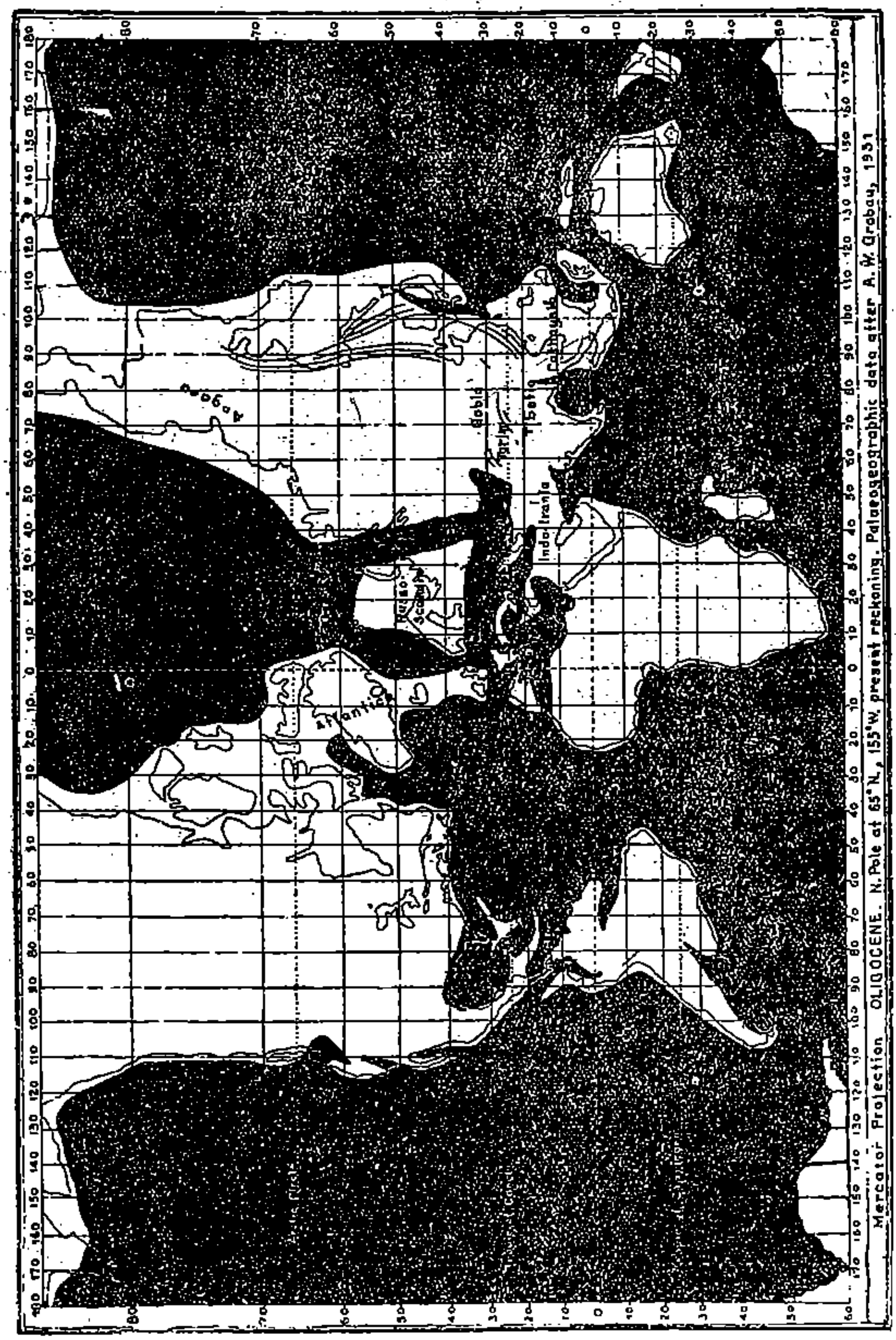


Mercator Projection—MID-MIOCENE. N. Pole at 75°N., 150°W., present reckoning. Palaeogeographic data after A.W. Grabau, 1931

Figure 19

Figure 20

Explanation of conventions used in *Figures 19 and 20*: Miocene land masses, white, marine transgressions not persisting throughout the stages represented, white with oblique line-shading; Spirialis sea, dotted; oceans and seas, black; trends of mountain systems, fine continuous black lines: outlines of present-day land masses as in *Figures 11 and 12*.



Mercator Projection. OLIGOCENE. N. Pole at 65°N., 155°W. present reckoning. Palaeogeographic data after A. W. Grabau, 1931

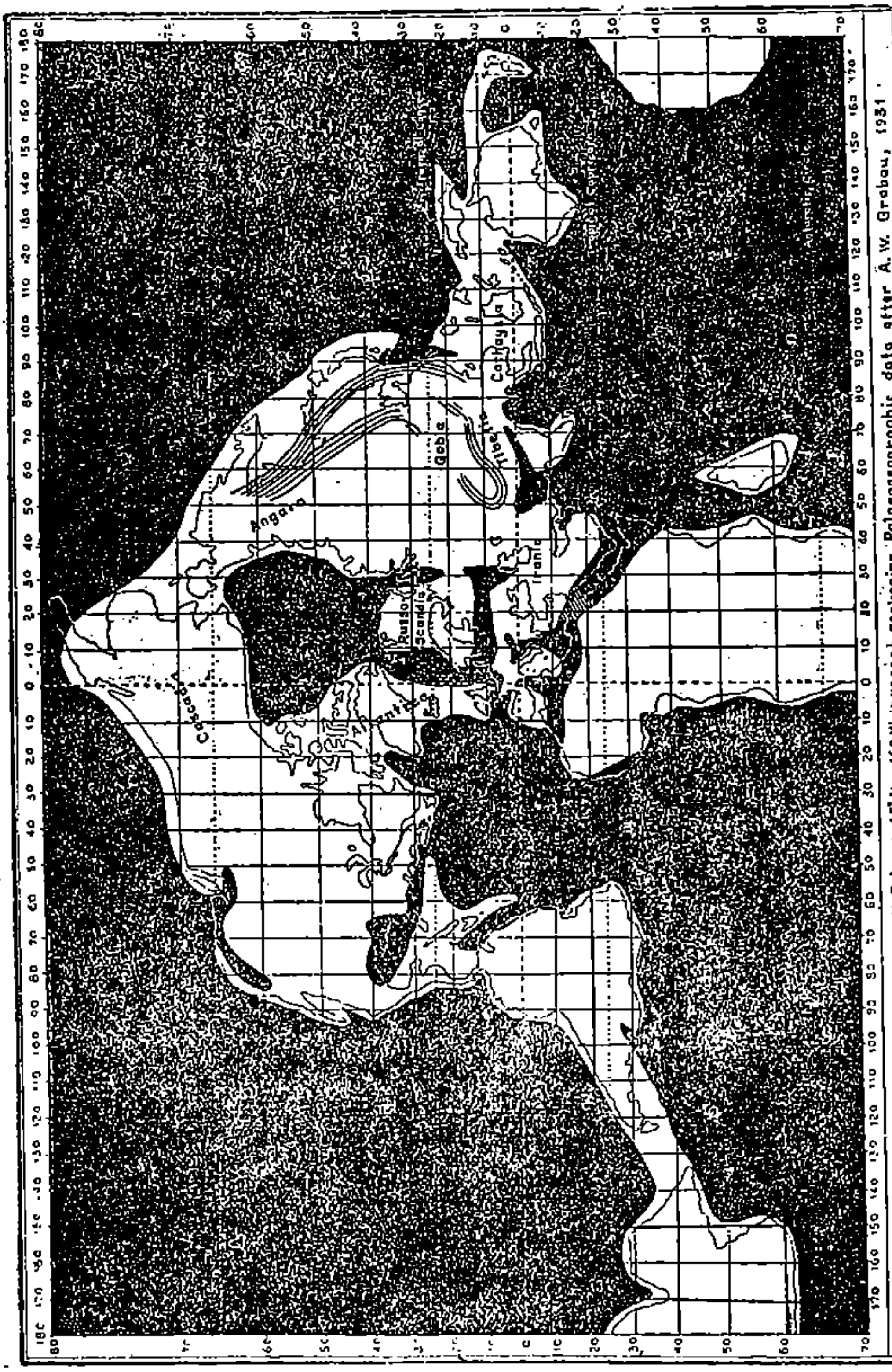
Figure 22

Explanation of conventions used in *Figures 21 and 22*: Oligocene land masses, white; oceans and seas, black; trends of mountain systems, fine continuous black lines; outlines of present-day land masses as in *Figures 13 and 14*.


EOCENE. N. Pole at 45°N., 180°W. present reckoning. Palaeogeographic data after A. W. Grabau, 1931
Mercator Projection
Angara
Gobia

Figure 23

Figure 24
Explanation of conventions used in *Figures 23 and 24*: Eocene land masses, white; oceans and seas, black; trends of mountain systems, fine continuous black lines; outlines of present-day land masses as in *Figures 15 and 16*.



Mercator Projection PALÆOCENE. N. Pole at 45°N., 160 W. present reckoning. Palaeogeographic data after A. W. Grabau, 1931.

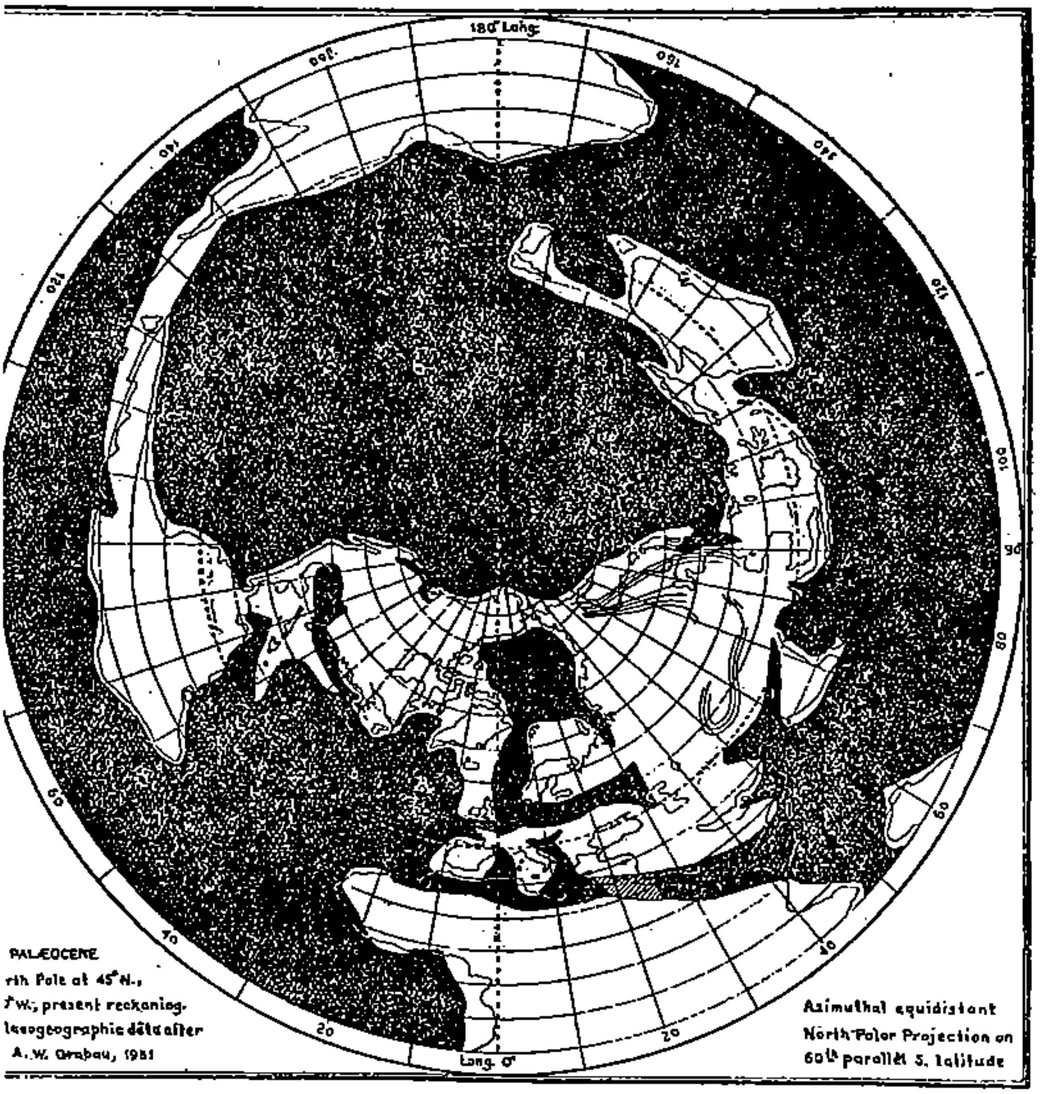


Figure 26

Explanation of conventions used in *Figures 25 and 26*: Palaeocene land masses, white; marine transgressions not persisting throughout stage represented, white with oblique line shading; oceans and seas, brack; trends of mountain systems, fine continuous black lines; outlines of present-day land masses as in *Figures 15 and 16*.