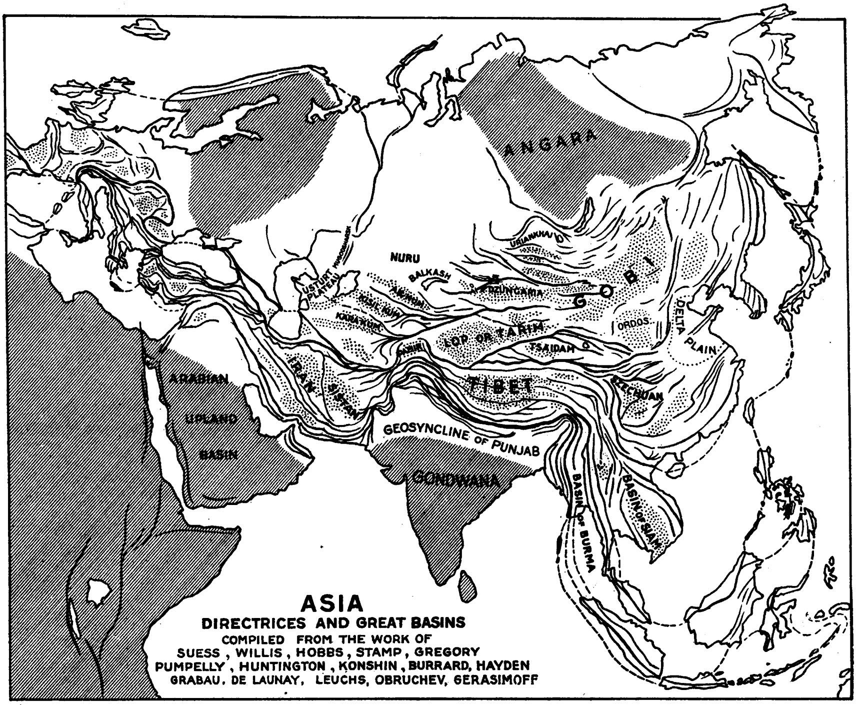


Fig. 1. Map of Asia, showing the trend of mountain ranges, and the position of the great basins.

Large positive elements are shaded in slanting lines. The great structural basins are stippled.

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# Article V.—BASIN STRUCTURES IN MONGOLIA[1]

By Charles P. Berkey and Frederick K. Morris

## CONTENTS



[1]Publications of the Asiatic Expeditions of The American Museum of Natural History. Contribution No. 29.

# INTRODUCTION

Between the vast areas of Asia enjoying ocean drainage lies a series of great interior basins of diverse type, extending from the Amur headwaters in the northeast to the Caspian in the southwest; and from the Arctic divide to the Himalayas. These basins, as indicated on the accompanying map (Fig. 1), are the Gobi, the Dzungaria (or Sinkiang), the Lop (Tarim or Taklamakan), the Balkash and Aral-Caspian, besides high intermontane basins like Tibet and Iran. All these are semiarid steppe-countries, including desert ranges, broad, open minor basins, and occasional depressions with lakes and salt pans.

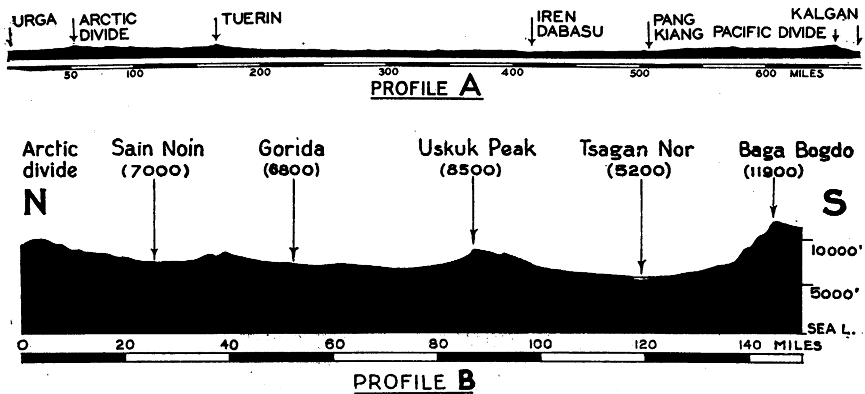


Fig. 2A. Profile across the Gobi region between Kalgan and Urga, showing a broad, very shallow downwarp between the Arctic and Pacific divides. Vertical scale × 10.

B. Profile across the northern part of the Gobi region, between the Khangai and Altai mountain ranges, showing stronger warping and block-faulting in this part of the great basin than in the eastern section. Vertical scale × 10.

The Gobi, easternmost of the great basins, has a width of, roughly, 500 miles north and south, and a length of 1,000 miles east and west. The entire country from the southerly margin to the Arctic divide is warped into a gently sloping concavity, or broad open syncline, whose central portion is 3,000 feet lower than the outer margins. Thus the rims of the basin stand from 5,000 to 7,000 feet above the sea, and the broad downwarped expanse between forms a basin-shaped plateau, parts of which are real desert. Generalized profiles are plotted in figure 2. We judge that the eastern profile represents almost pure warping, while the western profile is the result of warping plus extensive faulting in the midst of the original basin.

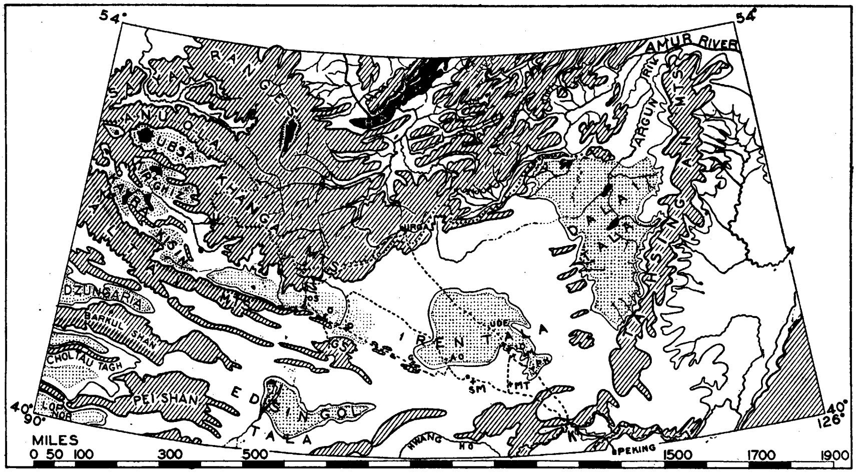


Fig. 3. Map of the Gobi region.

The mountainous areas are shaded with slanting lines. The lowlands are white, while the deeper depressions are stippled. This map serves as a location map for the talas named in the text, and also shows the routes of the Expedition. The index-letters have the following meanings: AO, Ardyn Obo; D, Djadochta; G, Golobai; GS, Gurbun Saikhan; ID, Iren Dabasu; IM, Irdin Manha; K (northwest of Peking), Kalgan; K (in the west, just north of the initial A of ALTAI), Kobdo; MT, Murukh Tchu; O, Oshih (Ashile); OS, Ondai Sair; PK, Pang Kiang; SM, Shara Murun; U (south of the K of KHANGAI), Uliassutai.

The great basin of the Gobi contains many minor basins, which we are calling "talas," from a Mongol word for an open steppe-country (Fig. 3). The following talas may be demonstrated: the Dalai Nor tala, now draining through the Argun river to the Amur; the Iren tala; the Gashuin Nor, or Edsin Gol tala; the Kisin or Shargin tala; the Khara and Dzapkhin, or Kirghiz Nor tala, in which are the cities of Kobdo and Uliassutai; the Tez, or Ubsa Nor tala. Each tala has its own local interior drainage and is bounded by inconspicuous warp divides or by mountain ranges, or both, separating it from neighboring areas of similar habit.

Again, within each tala there are still smaller basins, which contain sediments of late Mesozoic or Tertiary age, or both. These smaller units appear as broad level spaces whose surface is beveled by the Gobi peneplane, the remarkably smooth flat surface of which is one of the most striking features of Mongolia. These basins of the third order of magnitude are the units of special interest to this investigation. Inquiring of the Mongols as to the derivation of the word "gobi," it was found that such open level-surfaced basins are called "gobis," and we can think of no better term by which to call them in science. A cross section taken from one of the field books will serve to show the typical structure of such a minor basin, or gobi, in a restricted sense (Fig. 4).

## NATURE OF THE ROCK FLOOR

The oldrock floor is a complex of ancient sedimentary strata, metamorphic rocks and intrusive igneous masses, both large and small. The oldest rocks recognized by us are complex injection-gneisses, crystalline limestones and related rock types exhibiting the most complex structural conditions and mixtures of composition found in the whole region. They appear to be more deformed, more modified, and richer in injected igneous material than any of the other series, and they are the most confusing to interpret. They should be the oldest of all and may indeed correspond to the Archæan of other lands. On these grounds they are judged to be Archæan, and to represent the T'ai Shan complex described by Willis and Blackwelder as occurring in China proper.[1]

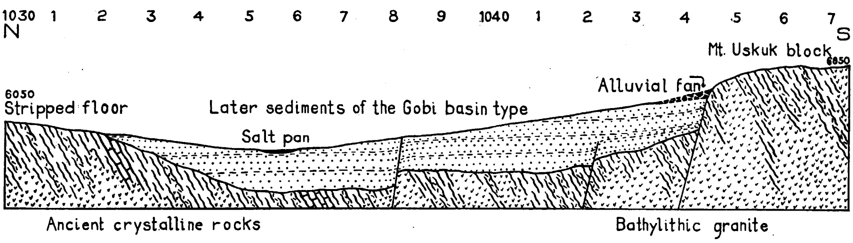


Fig. 4. Cross section from the geologist's field notebook, showing the basin north of Uskuk Mountain.

Ancient crystalline rocks—gneisses, schists and interbedded limestones, invaded by granites representing the Great Mongolian Bathylith, form the warped floor on which later sediments have been accumulated. Further deformation with faulting has affected the basin, pushing up the Mt. Uskuk block and making possible development of alluvial fans. Erosion has stripped some of the floor and has carved a broad shallow valley in the sediment, in the almost abandoned depressions of which a salt pan is located. This section is almost continuous with Fig. 10, which lies south of the Uskuk block.

The next younger series includes schists and crystalline limestones which are found in the Tsetsenwan hills. Between Shara Murun and Ardyn Obo, there is a great series of greenstones and phyllites which we consider to be older than the Khangai graywackes next to be described. The fact that these series have not been observed in close contact with one another makes it difficult to determine their exact relations. They are very clearly more intensely modified by metamorphic processes and constitute a more varied series than does the graywacke series referred to as the Khangai, and they evidently belong to a more ancient geologic time. Perhaps the early Proterozoic system, the Wu T'ai Shan, as used in China, is large enough to hold them.

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[1]Willis, Bailey, Blackwelder, Eliot, and Sargent, R. H. 1907. "Research in China," I, pp. 19, 59, 99, 157; II, p. 1; Carnegie Institution of Washington, Pub. 54.

The most widespread sedimentary unit was given the field name "Khangai series," from a range of mountains of that name on the Arctic divide. The total thickness of the series is not less than 20,000 feet. It consists almost wholly of graywackes, siliceous argillites and slates. Locally, red jasper or blue siliceous limestone is found with these strata, but these types do not figure heavily in the series as a whole. The rocks are not very highly metamorphosed, and yet they are surprisingly unfossiliferous. The immense extent, great thickness and uniform character of this formation are most impressive. The strata are everywhere strongly folded, and because of the lack of fossils, together with the general structural relations, are judged to be late pre-Cambrian—possibly to be correlated with the Nan K'ou of Richthofen and Bailey Willis,[1] or the Sinian of Grabau,[2] as described for China.

Besides many minor intrusive bodies, all these series of rocks are cut by an immense bathylith, dominantly granite, the great stocks of which are exposed over broad areas. Apophyses from it were found as far north as the Khangai range and the Gangin Daba and Olon Obo mountains, and it is our belief that the granite of Nan K'ou Pass above Peking belongs to the same unit. Possibly this bathylith is genetically responsible for the mineralization of the gold veins north of Urga and in the Uliassutai country.

Overlying these formations unconformably are marine limestones, limy shales and sandstones with fossils of Mississippian, possibly of Pennsylvanian, and certainly of Permian age. All are very complexly folded and faulted and have been almost completely swept away in the course of later erosions. Only two comparatively small infolded synclinal and graben-fault remnants of the sedimentary formations of this short-lived, but significant, Paleozoic geosyncline were found in Mongolia. A few dikes cut these beds, but no large intrusives seem to have reached them.

Unconformable, also, upon the pre-Paleozoic rocks, is an extensive and persistent series of continental conglomerates, sandstones and minor shales, with interbedded tuffs and surface flows, the aggregate thickness of which is in places more than 10,000 feet. Obscure woody plant-remains are found in these coarse clastics, and at one locality several thin seams of coal were seen. All are strongly folded and the question may be raised whether the same disturbance folded these that plicated the marine

[1]von Richthofen, Ferdinand Freiherr. 1882. "China," II, pp. 316–317, Berlin. Willis, Bailey, Blackwelder, Eliot, and Sargent, R. H. 1907. "Research in China," I, p. 123, Carnegie Institution of Washington, Pub. 54.

[2]Grabau, A. W. 1922. "The Sinian System," Bull. Geol. Soc. China, I, p. 44.

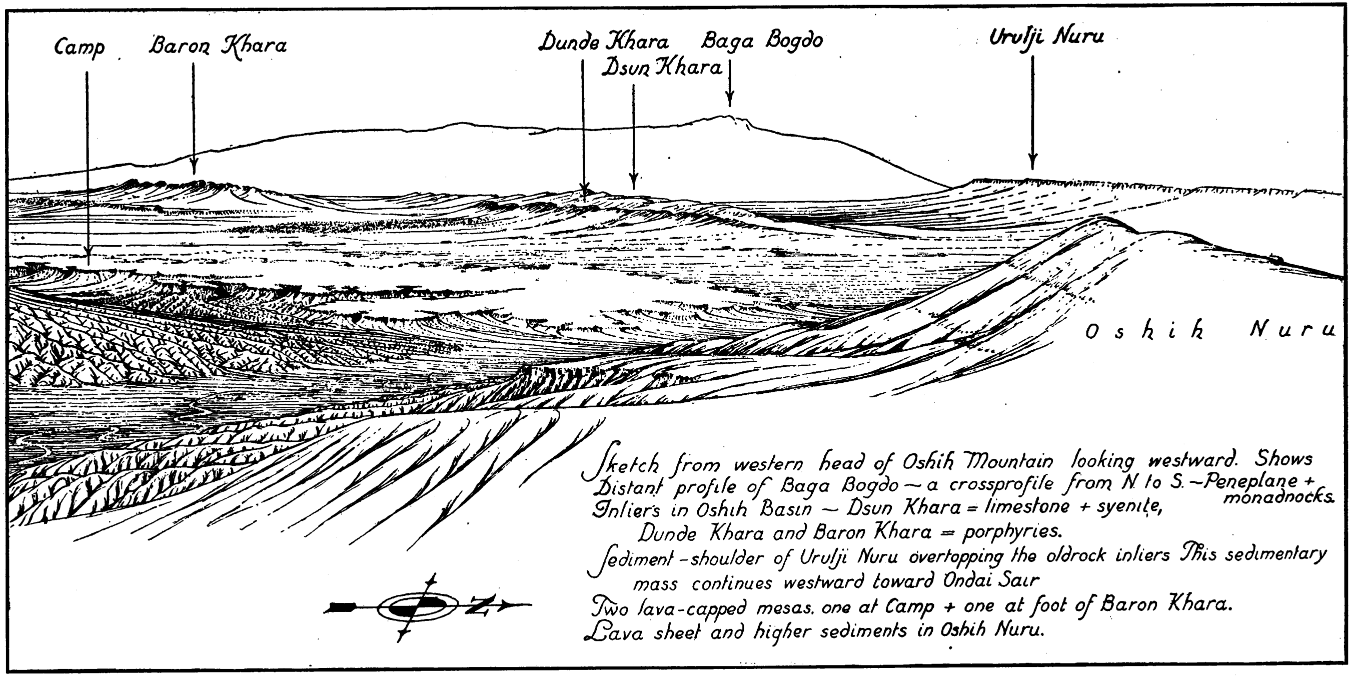


Fig. 5. Sketch in the Oshih basin, looking westward.

Baga Bogdo, seen in profile from north to south, shows the narrowness of the Altai range in this dimension. Two low ranges of hills in the middle distance consist, the one of folded trachyte porphyry, and the other of crystalline limestone, cut by syenite. The high shoulder at the right, called Urulji Nuru, represents sediments that once extended over the hard-rock ridges. At the foot of these ridges are two areas of badlands, the southern one capped by a lava sheet. The lava reappears in the broad mesa in the center of the sketch. A fault runs along the nearer front of this mesa, and the edge of the lava bends notably downward toward the spectator. The edge of the faulted lava sheet reappears in Oshih Mountain in the extreme foreground. The sketch emphasizes the unevenness of the old floor and the enormous amount of sediment that has been stripped from it.

Paleozoic beds. At another time, we may submit evidence for the view that the two series were folded at different times and that the conglomerate series is approximately of the same age as the folded coal-bearing conglomerates and shales of northern China, which are conceded to be of Lower Jurassic age. The latest mountain-folding, then, follows the development of these Jurassic strata and, if this correlation proves admissible, must be of Middle or late Jurassic date.

At this point in the geologic column, a complete change of structural behavior takes place. All earlier rocks are mountain-folded and extensively deformed, whereas those strata that lie above them are not folded at all, and, although they are tilted and warped, or broken, they are only locally much deformed even in this way. The Jurassic unconformity marks, therefore, the most significant break in the whole geologic column for central Mongolia. It marks the change from repeated deformative revolutions to a state of much greater stability and the establishment of a continental history that has persisted unbroken to the present day.

## BASIN SEDIMENTS

All these older disturbed rocks were worn down to a mature, rolling, locally baseleveled surface before the first of the nearly horizontal sediments in which we find vertebrate fossils was laid down. A sketch (Fig. 5) made in the Oshih (Ashile) basin, oldest of the gobis, shows, besides sediments and an interbedded lava flow, two inliers, one of the pre-Cambrian limestone, the other of possible Jurassic porphyry flows; both have been brought into view by the stripping away of the sediments rather than by local uplift or by faulting. The later sediments, such as those of Urulji Nuru, doubtless once covered the tops of these inliers and probably even such mountain groups also as the more distant Baga Bogdo, Artsa Bogdo, and the Gurbun Saikhan,—the easterly representatives of the Altai mountain range.

The Oshih beds contain sauropods and primitive armored dinosaur bones and may prove to be Lower Cretaceous (Comanchean) in age.[1] The sediments are entirely of inland continental type—sands, gravels, clays, paper shales, gypsum-bearing clays—and of moist to semiarid climatic association. The entire fauna is non-marine and very difficult to correlate with the faunas of other regions. It clearly represents an inland, relatively isolated basin.[2] At this remote time, then, Mon-

[1]Osborn, Henry Fairfield. 1923. "Two Lower Cretaceous Dinosaurs of Mongolia." Amer. Mus. Novitates, No. 95, pp. 1–10.
[2]Reis, O. 1910. "Die Binnenfauna der Fischschiefer in Transbaikalien." Explor. Géolog. Chemin de Fer, Sibérie, Petrograd. Cockerell, T. D. A. 1924. "Fossils in the Ondai Sair Formation, Mongolia." Amer. Mus. Bull. (in press).

golia and Angara were dry land, warping into inland basins at first of swampy deposition, with lacustrine and flood-plain types predominating, but later and intermittently developing more pronounced aridity.

## ORIGIN OF DEPRESSIONS

In a paper now in preparation, we discuss the origin of depressions in the Gobi desert of to-day, and attempt a review of the literature on this subject. A brief statement must suffice for the present.

The text of this paper will make it clear that the basins cannot all be of the same age; it is very improbable that just the same climates prevailed during all the periods recorded by basin sediments, although we shall offer evidence in another paper to support the thesis that the climate of Mongolia in the past has varied between relatively narrow limits,—between semiarid and desert conditions. It is improbable, furthermore, that the relief was similar in all the periods represented, but it must have ranged from a peneplane to a surface rugged enough to provide coarse rubble. The part played by warping has been touched upon. The basin or depression which now contains the sediments is not by any means coextensive with the original area over which those sediments were deposited, yet we must deal primarily with the basins that have retained sediments to the present day.

We believe that the basins of deposition were not of simple origin, but were the resultant of a number of interacting agencies. To choose a single general case as an illustration, let us suppose, in Tertiary time, a region of moderate relief, including areas of oldrock and of basin sediments, dissected in part by stream work and in part by deflation. The following variable quantities will enter into the problem:—

1. Greater and lesser depth of eroded hollows.
2. Greater and lesser areas of hollows.
3. Hollows or depressions in oldrock areas, where all the sediments deposited in the hollow must be derived from the slow decay of the hard rock. This introduces in turn a new variable, the amount and character of loose material available in the hard rock area. A long quiescent period, and especially a moist climatic rhythm, would have developed a good mantle of soil.
4. Hollows in or near sediment basins, where easily eroded material may be washed out or blown out, offering a great supply of sediment.
5. Disposition, no less than amount, of water supply.
6. Relation of prevailing winds to source of sediments.

Independently of all these variables, it seems necessary to introduce the hypothesis of periodic warping, as will be made clear in the pages that follow.

In figure 6 we show a region of low, mature relief, broad lowlands or hollows alternating with higher regions. In figure 7 these are warped into very gentle swells and depressions, which, save by chance, bear no relation to the topography. Where a downwarp coincides with a lowland, as in figure 7, A-B, the condition will be most favorable to the retention of sediment, and the basin will be filled. Where an upwarp coincides with high ground, as in figure 7, C-D, a broad divide will be formed, from which debris will be washed into surrounding regions. If an erosion-hollow is upwarped, its resultant behavior will depend roughly

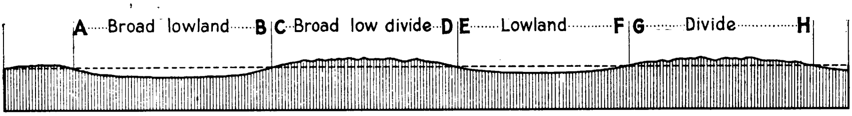


Fig. 6.

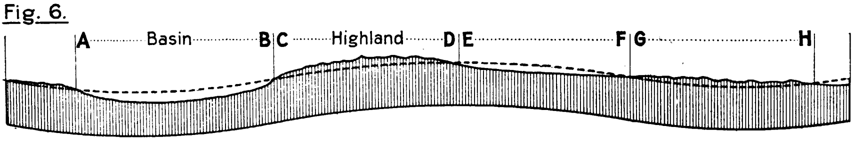


Fig. 7.

Fig. 6. Lay figure of a maturely dissected region of low relief, before warping.

Fig. 7. The same region, after warping,—showing how basins and uplands may be the result of original relief and deformation combined.

Let both higher relief and upward movement be denoted by the + sign, while lowland and downwarp are denoted by the — sign. Then in A-B, both relief and movement are negative, so that a basin is formed. In C-D, both influences are positive, while in E-F and G-H, positive and negative elements combine, making either basin or highland according as the relief factor is greater or less than the warping. Thus in the Oshih basin, Fig. 5, ridges of hard-rock have formed part of the lowland, and have been covered by sediments.

upon the algebraic sum of two opposite influences, the depth of the hollow and the amount of uplift. Thus, if the upwarp is less than the depth of the hollow, as in figure 7, E-F, the hollow still remains, though diminished as a possible repository of sediments. Where a divide is downwarped, it will be included in a basin and will be covered over with sediments, if the downwarping considerably exceeds the height of the divide; otherwise it may still remain a divide.

If we suppose that, in general, the basins formed where all the conditions were most favorable, the amount of warping that need be assumed would be reduced to a minimum. The relative part played by wind and water in the erosion of primary hollows or valleys forms an important subject in itself, and a report on the evidence is in preparation.

## TYPES OF GOBI BASINS

Two types of gobi basin are distinguished: first, the faulted or piedmont gobi basin, found along the base of the fault-block mountains of the Altai; and second, the warped or plains type, in the less disturbed areas. The types are not sharply demarked from one another, but the distinctions are instructive.

1. The faulted, or piedmont, gobi basins are distinguished by: (a) greater thickness of sediment; (b) great range in texture of sediment,—including paper shale, fresh-and-brackish-water limestones, clay, sand, gravel and coarse rubble, even with great bowlders; (c) wide range of time-periods represented in the sediments,—which implies longer life of the basin as a locus of warping; (d) igneous flows, which are common

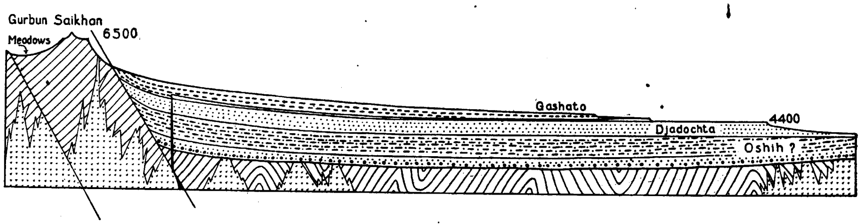


Fig. 8. Cross section of the Djadochta region.

This is a simple faulted type of gobi basin. The beds near the mountain front dip 56° north. Younger beds are encountered as one goes toward the mountain front. In this respect the basin is comparable to the Baga Bogdo piedmont basin, Fig. 10. It is not positively known that Oshih beds underlie the Djadochta; their presence is inferred. Compare with Fig. 11.

in these basins. Volcanism seems to have been associated with faulting, and all the more disturbed basins observed by us contain lava flows (Fig. 8).

2. The warped, or plains, gobi basins are shallower and contain thinner sediments, of but few periods, so that the gaps in the geologic record are even larger than in the sediments of the piedmont basins. The range in coarseness of sediment is less wide—sandy clay, sands and small-pebble gravels predominate. In addition, there are a few occurrences of fresh-water limestones, dense limy marl, marly sandstone, and thin beds of gypsum. None of the warped basins has been markedly disturbed by faulting or tilting.

None of the basins of either type contains a complete record of the sedimentation; none even contains all the horizons represented in Mongolia. In each basin, the sedimentary formations are separated by disconformities or by angular unconformities, representing long gaps or erosion-intervals in the geologic record.

These facts will be considered in some detail, and will be marshaled in support of three theses, as follows:

1. Warping took place in a series of successive increments of movement, separated by pauses or intervals of quiescence long enough in some instances to permit the peneplanation of faulted and warped sediments, and to allow for a complete change of fauna.

2. The locus of warping shifted from place to place; that is, after deposition of one formation in a given basin, warping did not as a rule continue in that basin, but rather in another place, which, in turn, having received a shallow filling of sediment, passed into a quiescent period, and

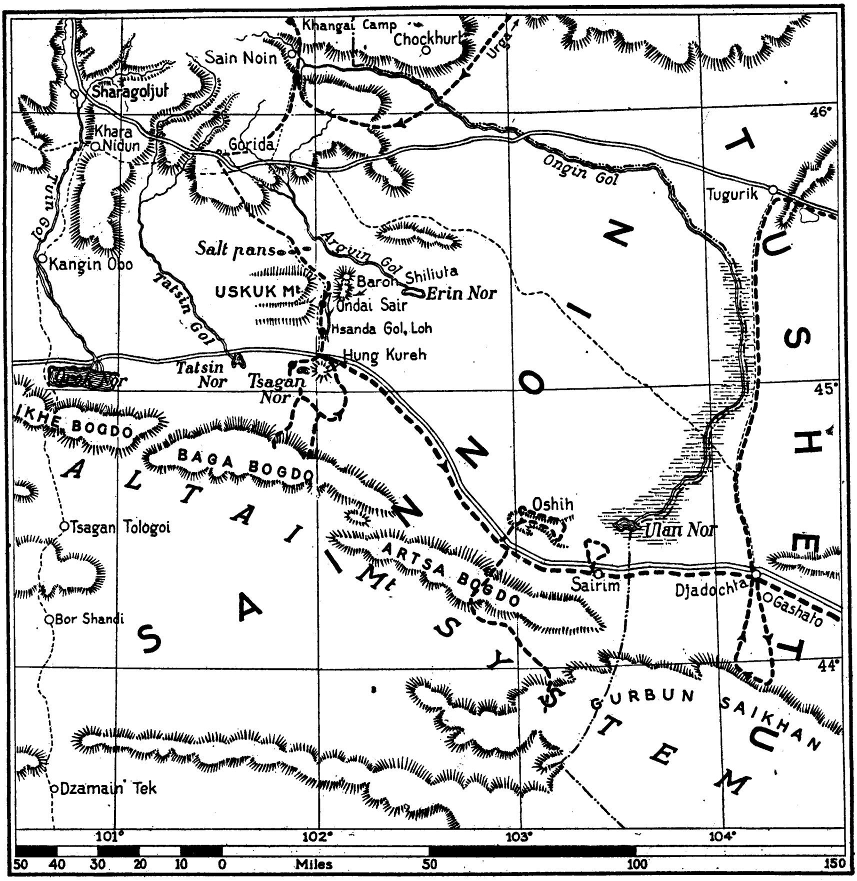


Fig. 9. Sketch map of the eastern Altai region, showing location of stations mentioned in the text.

The limits of the sediment basins are not sufficiently known to justify an attempt to draw them.

the next locus of deposition was in still another basin, or possibly back in the first. Each basin had its rhythm of alternating deposition and quiescence, which probably implied removal of part of the earlier deposit. Some basins, however, continued to warp intermittently during longer periods of time than others.

3. Small units, such as the Mongolian gobi basins, carrying shallow sedimentary fills, probably cannot of themselves set in motion the deep-seated shift of material required by the theory of isostasy. It is not improbable that we sometimes overestimate the effect of the positive weight of the sediments, as well as of the negative load due to stripping of up-arching areas, as the actuating causes of warping. This thesis does not imply that the authors do not accept the principle of isostasy as applying to earth movements of the first magnitude.

We will describe two basins briefly, a faulted or piedmont basin, and a warped or plains basin.

### Faulted or Piedmont Type of Gobi Basin

Each of three ranges of the eastern Altai, the Baga Bogdo, Artsa Bogdo and Gurbun Saikhan, presents essentially a fault-front along its northern margin (Fig. 9).

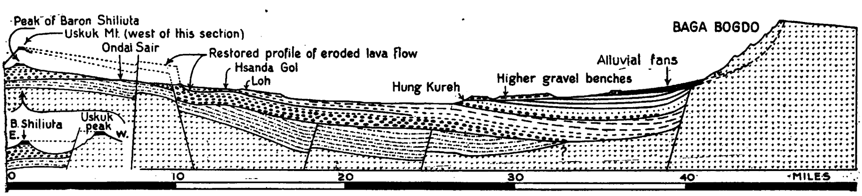


Fig. 10. Cross section of the Baga Bogdo faulted gobi basin.

Though on a much smaller scale, this section is almost continuous with Fig. 4, lying south of the latter. The Uskuk fault-mountain lies just west of the section and so is drawn in dotted lines. Part at least of the sediments once rested upon the Uskuk block, because remnants of sediments have been found upon it, and apparently the same lava flow that is seen in the sediments caps the granite of Uskuk peak. These relations are indicated in the dotted lines. The lava-capped butte, Baron Shiliuta, is seen projected against the higher peak of Uskuk. A short cross section, oriented east-west, is introduced to show the relation between these two peaks. The Cretaceous Ondai Sair beds are much more deformed than the Tertiary formations, which overlie them unconformably. Tertiary beds are also deformed by both faulting and warping. The southern part of the section, between Hung Kureh and Baga Bogdo, is much more disturbed than is represented in this drawing, and carries the latest sediments of the region. The Gobi peneplane is highly developed in this district, and is itself deformed. Since the peneplane bevels Pliocene beds, this section is one of our best means of determining the date of its formation.

In the Baga Bogdo piedmont basin (Fig. 10) the following section is recorded, from oldest to youngest:[1]

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[1]Berkey, Charles P., and Granger, Walter. 1923. "Later Sediments of the Desert Basins of Central Mongolia." Amer. Mus. Novitates, No. 77.

1. The oldrock floor, consisting of schists, marbles, graywackes and slates, all of diverse pre-Cambrian age invaded by granite. Infolded in this complex are conglomerates and sandstones, locally containing seams of coal, which are judged to be Lower Jurassic in age. These form part of the rock floor, not part of the basin sediments.

2. The Ondai Sair sands and paper shales, of Lower Cretaceous (Comanchean) age, resting upon the old floor. They are at least 500 feet thick, and are faulted and tilted.

3. About 3,500 feet of early Tertiary gravels, sands and sandy clays resting unconformably upon the Ondai Sair. They include at least one lava flow, and are in places uptilted and faulted, but they do not share all the disturbances of the Ondai Sair. The higher beds carry the Lower Oligocene *Baluchitherium* fauna, and are called the Hsanda Gol formation, a name which is provisionally extended to the base of the conglomerates, though the lower beds may yet prove to be Eocene.

4. The Lower Miocene clays of Loh, less than 100 feet thick, resting upon the Hsanda Gol clays, without any obvious physical disconformity. Going southward along their dip (Fig. 10), we found that they were succeeded by an undetermined thickness, probably as much as 1,000 feet, of sandy clays and sands, in which as yet no fossils have been found.

5. The Hung Kureh sands and clays, about 2,000 feet thick, gravelly toward the base of the exposure. They carry a fauna of late Pliocene age, according to the opinion of Mr. Walter Granger, paleontologist of the Expedition. They have been disturbed by tilting and faulting, which may be of the same age as that which deformed the older Tertiary beds, but which are probably of later date.

6. A mantle of coarse rubble, clearly derived from Baga Bogdo. This coarse rubble is at least 2,000 feet thick, is partly consolidated, and is unfossiliferous, so far as we now know. Its age may be latest Pliocene or Pleistocene.

The thicknesses of all the formations exposed in the basin add up to 8,500 feet, but, since the whole thickness of some of the members is not known, it may be as much as 10,000 feet. Only a fraction of these strata was accumulated in any one period, yet this basin is the longest-lived and most active basin yet observed in Mongolia, containing the oldest and the youngest basin sediments of which we have record.

Among the features that bear upon the problem of basin-structure may be mentioned the following:

1. The sedimentary formations dip toward the Altai, and younger beds are encountered as we go southward toward the Altai front.

2. The conglomerate at the base of the Tertiary consists of well-rounded pebbles that were derived almost certainly from the Jurassic conglomerate of the general Uskuk region. It would seem that these beds were washed into the basin from the north, rather than from the south, implying that the present Altai was not a notable range in the early Tertiary.

3. The Hung Kureh formation consists of fine materials everywhere except toward the base, where it grades into gravel, and therefore indicates no very marked relief in the Altai region in Pliocene time. The first evidence of rugged relief is the deluge of coarse rubble overlying the Hung Kureh.

We infer from these facts that deformation has been secular and progressive, with long periods of quiescence alternating with periods of disturbance. Thus faulting and tilting took place after the Lower Cretaceous (Comanchean) and after the Pliocene, at least, and possibly after the Miocene as well.

An even more suggestive example is found in the Oshih and Djadochta divisions of the Altai piedmont basin. The Oshih is the piedmont basin of the Artsa Bogdo range. Here are about 2,000 feet of very considerably faulted and tilted sediments. The faults are of small throw, ranging from five feet to 200 feet, and in one instance possibly even more; the dips, apart from drag in the fault zones, do not exceed 24°, and are for the most part 10° or less. The Oshih contains fossils of about the same age as the Ondai Sair and is almost undoubtedly continuous with it.

South of the Artsa Bogdo range lies a basin whose sediments contain reptile bones, which Granger judges to be of Oshih age,—indicating either a former extension of the Oshih basin over the site of the present Altai, or an entirely different basin separated from the northern Oshih by a Lower Cretaceous divide.

North of the Gurbun Saikhan, about forty miles east of Oshih, lies a piedmont basin whose floor is not exposed, so far as observed. This basin contains the Djadochta sands, of Cretaceous age, with the *Protoceratops* fauna and the dinosaur eggs. The sand of the Djadochta is very fine, of uniform red color, and about 500 feet thick. The beds dip gently southward into the Gurbun Saikhan piedmont basin, and have been very faintly tilted and arched, but not faulted.

These sands cannot have been derived from the direct weathering of the Gurbun Saikhan, which is composed of such rocks as graywackes, argillites, phyllites, limestones, serpentines and diorites. They must have been derived instead from a preëxisting sand that had already undergone

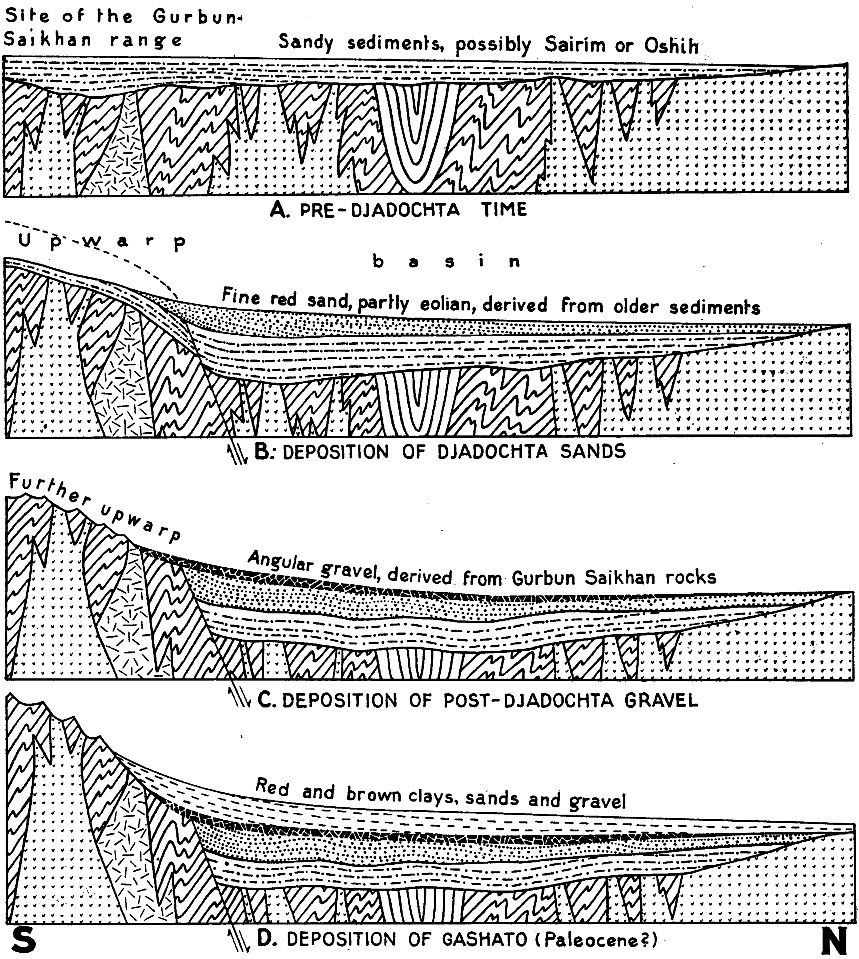


Fig. 11. Four stages of warping indicated in the Djadochta basin.

A shows an old basin of sandy sediments deposited upon a floor of complex old rocks. B shows initial upwarp that caused the Djadochta sands to be washed down into the newly formed basin, without, however, exposing crystalline rocks of the present Gurbun Saikhan range. C shows the deposition of a gravel of angular pebbles, derived from the Gurbun Saikhan rocks, and hence implies that those rocks have been laid bare. D shows the deposition of the Eocene Gashato beds, the peneplaned remnant of which is at least 300 feet thick, and may be much more. The structure of the rock floor of the basin is inferred from the granite exposed to the north of the basin, and the rocks observed in the Gurbun Saikhan range. The successive warpings of relatively small throw suggest the method by which this wing of the Altai was made.

considerable assorting. The only earlier sand of which we have knowledge in the region is the Oshih. Now the highest member of the Oshih that we have seen is a red-and-white sand, called the Sairim member, which is strikingly similar to the Djadochta sand in composition and texture.

Its present easternmost outcrops lie less than forty miles from the present westernmost outcrops of the Djadochta, and both formations must have been more extensive in the late Mesozoic. We suggest that the Oshih, at least in its upper members, may once have overlapped the present site of the Gurbun Saikhan (Fig. 11A). It is not improbable that when uplift began in early Djadochta time, the present Gurbun Saikhan rocks were not exposed, but that the overlying Oshih sands were eroded and washed into the newly formed basin, to become the Djadochta deposits (Fig. 11B). As evidence for this view, we cite the facts that a gravel of angular pebbles overlies the Djadochta, and that these pebbles are all of Gurbun Saikhan origin, which suggests that the next, post-Djadochta, increment of warping brought the Gurbun Saikhan rocks to light (Fig. 11C).

The age of these gravels is known approximately, since they lie underneath the Gashato clays and gravels which carry an early Eocene fauna, according to identifications by Granger (Fig. 11D).

Therefore, the chief dates of warping in this basin fall: (1) in Oshih (Lower Cretaceous) time, when the pre-Djadochta sand-terrane was being deposited over a large part of the eastern Altai region; (2) in Djadochta time (early Cretaceous ?); (3) in post-Djadochta time, when the Gurbun Saikhan rocks emerged; (4) in Gashato (early Eocene) time.

### Warped Type of Gobi Basin

The Irdin Manha basin includes the Iren Dabasu, limited on the north by slate hills, and the Shara Murun, limited on the west by complex old crystalline rocks. The southern boundary consists of hills of granite, schist and graywacke. We have not seen its eastern boundary, but the basin covers an area of at least 10,000 square miles (Fig. 12).

Within the basin is a succession of sediments which do not extend throughout the basin, but which overlap in a complex manner, each occupying a special area (Fig. 13).

The oldest sediment is the Iren Dabasu, of late Cretaceous age, not more than 180 feet thick, resting directly upon the crystallines. It is succeeded by lake beds which, though nearly barren of fossils, yielded a tooth of a small lophiodont, which should prove them Eocene. Upon these barren rocks rest the Lower Oligocene Houldjin gravel, here fifteen feet thick, but apparently thickening northwestward to fifty feet or more.[1]

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[1]Matthew, W. D., and Granger, Walter. 1923. "The Fauna of the Houldjin Gravels." Amer. Mus. Novitates, No. 97.

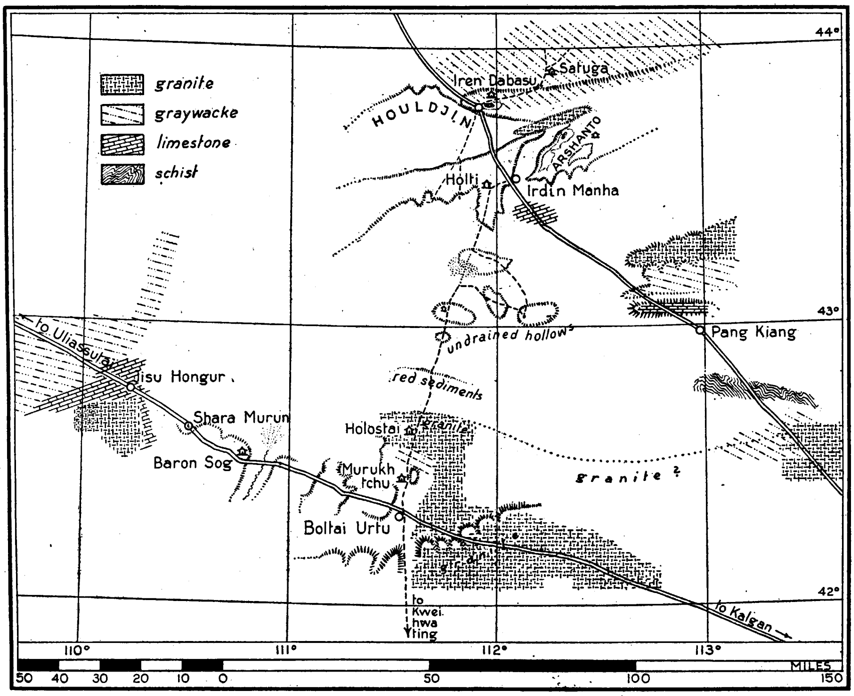


Fig. 12. Sketch map of the Irdin Manha region.
**This map serves to locate the stations mentioned in the text, but not to delimit the basin.**

At Irdin Manha, twenty miles southeast of Iren Dabasu, the Houldjin is not found, and the section exposed consists of 40 to 100 feet of gray sands, with a rich titanothere fauna, which may be late Middle or even Upper Eocene.[1] Beneath the titanothere beds there are red clays, provisionally called Arshanto, and probably to be correlated with the barren beds above the Iren Dabasu. The Arshanto may prove to be only the lower Irdin Manha, or it may be separated from the Irdin Manha by a disconformity. The base of these beds has not been seen.

The Pang Kiang beds, 60 miles farther south, are about 500 feet thick. In some places at least they rest directly upon the old crystalline rocks. Only one fossil has been found in the Pang Kiang, a fragment of a rodent jaw. Dr. Matthew identifies this as an ochotonid, which is in-

[1]Granger, W., and Berkey, C. P. 1922. "Discovery of Cretaceous and older Tertiary strata in Mongolia." Amer. Mus. Novitates, No. 42.
Berkey, C. P., and Granger, W. 1923. "Later Sediments of the Desert Basins of Central Mongolia." Amer. Mus. Novitates, No. 77.
Osborn, H. F. 1923. "Titanotheres and Lophiodonts in Mongolia." Amer. Mus. Novitates, No. 91.
Matthew, W. D., and Granger, W. 1924. "New Carnivora from the Tertiary of Mongolia." Amer. Mus. Novitates, No. 104.

sufficiently diagnostic to serve as an index of the exact age of the formation. He says, however, that this jaw could hardly be older than Miocene.[1] The exact relations of the Pang Kiang to the Irdin Manha must await further field study.

About 75 miles south of Irdin Manha, and 50 miles southwest of Pang Kiang, at the temple Murukh Tchu, a group of clays and sands lies directly upon the crystallines. About 150 feet are exposed, but the thickness may be 200 feet. No fossils were found in these beds.

Twenty-five miles south of Murukh Tchu, at Boltai Urtu, a great mass of conglomerates, about 1,000 feet thick, rests upon the oldrock floor and dips westward and northward away from the oldrock rim of the

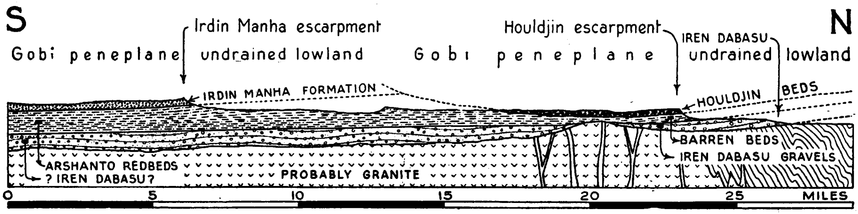


Fig. 13. Cross section of a repeatedly warped basin, from Iren Dabasu to Irdin Manha.

The section shows at least three periods of basin-making, and three unconformities. The unconformities lie (1) at the base of the Cretaceous Iren Dabasu beds, upon the uneven floor of crystalline rocks; (2) at the base of the Middle or Upper Eocene Arshanto (lower Irdin Manha) formation, upon the slightly disturbed Cretaceous beds, and even upon knobs of the old crystallines; (3) at the base of the Lower Oligocene Houldjin gravels, upon the eroded Eocene. Each unconformity implies a long period of quiescence before the deposition of the next succeeding sedimentary formation. The fact that the area became alternately a locus of deposition and of erosion seems to imply a periodic warping of the region. All thicknesses are twice exaggerated.

basin. These conglomerates pass northwestward under and interdigitate with sand and clay sediments which at Shara Murun bear a rich fauna of titanotheres and lophiodonts (Fig. 14). Professor Osborn regards this fauna provisionally as being somewhat younger than the Irdin Manha.[2]

These complex relations are represented diagrammatically in figure 15. No one place in this broad basin shows a complete section, even of the formations represented in the basin as a whole. All the formations are thin, their combined thickness probably nowhere exceeding 1,000 feet. In most parts of the basin it must fall short of this amount.

There are at least three gaps or breaks in the record, representing non-deposition or even removal of sediment: (1) pre-Cretaceous, a great unconformity, between the Iren Dabasu and the pre-Cambrian slates; (2) Cretaceous-Eocene, between the Iren Dabasu and the "barren

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[1]Personal communication.
[2]Personal communication.

beds" (Arshanto?); (3) Eocene-Oligocene, between the barren beds at Iren Dabasu and the Houldjin. Two other disconformities, of very minor value, may possibly be present,—one between the Arshanto and the Irdin Manha, and the other between the Irdin Manha and the Shara Murun.

The basin is not walled in by definite mountain uplifts, nor have we seen evidence to indicate that the hard-rock boundaries are faulted against the basin, except for very minor faulting at the southern boundary, 55 miles south of Iren Dabasu (Fig. 15). It represents, on the contrary, a broad, very gentle warping. The sediments now found in it have less than their former thickness, for the region has been peneplaned.

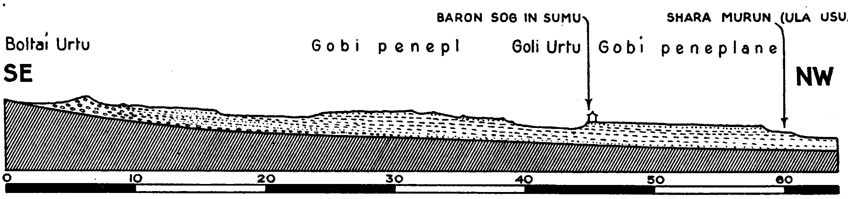


Fig. 14. Cross section of a warped gobi basin, from Boltai Urtu to Shara Murun (see map, Fig. 12).

The section shows conglomerates at Boltai Urtu resting directly upon the complex rock floor. These conglomerates die out westward, passing underneath, and grading into the sands and clays which at Shara Murun carry a rich fauna of Middle or Upper Eocene age.

The relation, too, of the sediments themselves suggests the former greater extent and thickness of the Houldjin at least, if not of the Irdin Manha also (Fig. 13).

The physical history of this great basin must consist of a series of gentle warpings followed by sedimentation, and the epochs of sedimentation were separated by longer periods in which sediments either were not laid down or have since been removed. In the epochs of filling, the deposition exceeded the removal of material from the basin, and this excess of deposition over removal is essentially the measure of warping. In the far longer quiescent periods, removal of material either balanced or exceeded the amount of sediment made available for the streams of that day, so that either no sediments were permanently retained in the region, or, more probably, part of what had been laid down in the preceding epochs of deposition was carried away. The absence of deep channels in the underlying sediments implies that the older beds were reduced to a smooth surface—a local peneplane—before the newer beds were laid down.

The vast lengths of time represented by the periods of quiescence or stability, the thinness of the sediments, the wide area covered and the absence of large faulting or great mountain uplift bordering these basins are all cited to support the thesis that the weight of sediments alone could not have caused the warping; first, because the thickness is too slight to have disturbed the isostatic equilibrium of the earth's crust, second, because the long periods of quiescence indicate that the crust sustained not only the positive weight of the sedimentary load without

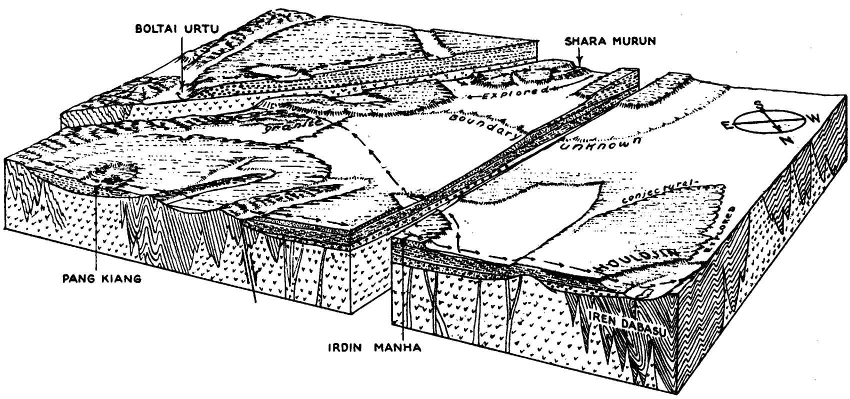


Fig. 15. Block diagram to show the general relations of the formations.

The left-hand or front edge runs northwestward and shows the basins between Pang Kiang and Iren Dabasu (compare with Fig. 13). The rear diagonal cut shows the section between Boltai Urtu and Shara Murun (compare with Fig. 14). The cut from front to rear shows one interpretation of the relations between the Irdin Manha and Shara Murun formations. It is possible that further studies by Osborn, Matthew and Granger may result in correlating these two formations.

being depressed by it, but also the negative load due to peneplanation without being uplifted. Instead, the next deposit of sediment, resting disconformably upon the older deposit, marks a new increment of downwarp following the peneplanation.

## GENERAL RELATIONS AND INFERENCES

Many other examples could be offered from every gobi basin we have studied, and all will be described in the larger report now in preparation. But we believe that the examples we have given are typical, and are enough to support the thesis that warping was a slow and discontinuous process, taking place by a series of small increments of movement; and that the sediments are to be correlated with the warping, recording, if the records could be read, both the upwarp that determined the removal of sediment from the upland, and the downwarp of the basin receiving it.

In figure 16 are plotted the thickness of sediments actually observed in the most important basins. Distances and directions between stations are plotted from the westernmost basin at the left to those along the Kalgan-Urga trail at the right. The column for China is generalized from J. G. Andersson's "Essays on the Cenozoic of Northern China."[1]

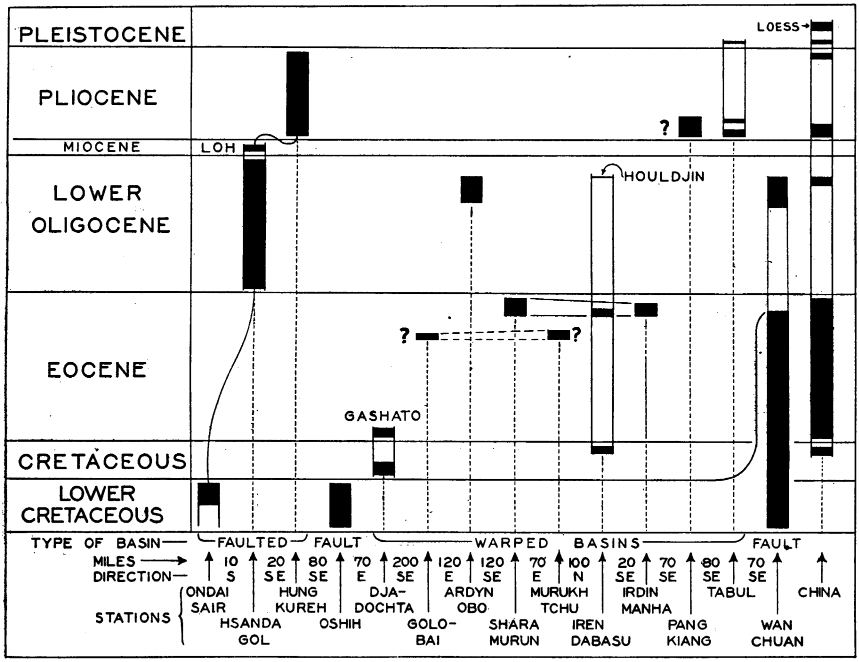


Fig. 16. Columnar diagram of the formations thus far observed in Mongolia.

Thicknesses are plotted to scale. It will be seen that the faulted basins contain far thicker deposits than do the warped basins. The diagram brings out clearly the shifting of the locus of deposition from place to place. The distances indicated at the bottom of the diagram are measured between stations or camps, not between the limits of the basins. The section for northern China is compiled from J. G. Andersson's "Essays on the Cenozoic of Northern China."

The diagram shows clearly the thinness of the sediments actually observed in contrast with the vast lapses of time involved. In figure 17 the columns for Mongolia are condensed into one for comparison as to thickness with those of the Rocky Mountain region, and with the American marine column, emphasizing the relative thinness of the deposits thus far observed in Mongolia.

Among the most interesting inferences which the facts support is the shifting of the locus of deposition from place to place. The Lower

[1] 1923. Mem. Geol. Surv. China, Ser. A, No. 3.

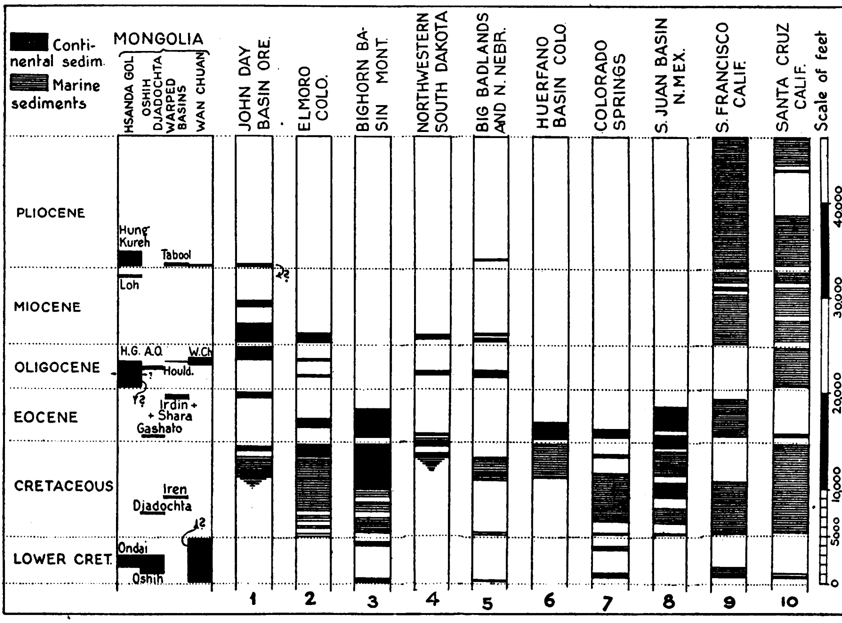


Fig. 17. The columns in Mongolia are shown in condensed form at the extreme left. The numbered columns represent typical sections in the western United States. Formations chiefly of marine origin are represented by parallel lines, while those chiefly of continental origin are in black. References are as follows:

1, Sinclair, W. J. 1909, quoted from Osborn, H. F. 1910. "Age of Mammals," p. 359.—2, Hills, Richard C. 1899. "Elmoro Folio, Colorado," U. S. Geol. Survey, Geol. Atlas, folio 58.—3, Fisher, Cassius A. 1906. "Geology and Water Resources of the Bighorn Basin," U. S. Geol. Survey, Prof. Paper 53.—4, Winchester, Dean E., Hares, C. J., Russell, Lloyd, and Parks, E. M. 1916. "The Lignite Fields of Northwestern South Dakota, U. S. Geol. Survey, Bull. No. 627, p. 16.—5, Darton, N. H. 1905. "Preliminary Report on the Geology and Underground Water Resources of the Central Great Plains," U. S. Geol. Survey, Prof. Paper 32. Wanless, Harold R. 1923. "The Stratigraphy of the White River Beds of South Dakota," Proc. Am. Phil. Soc., LXII, No. 4.—6, Osborn, H. F. 1897. "The Huerfano Lake Basin, Southern Colorado, and its Wind River and Bridger Fauna," Bull. Am. Mus. Nat. Hist., IX, Art. 21.—7, Finley, George I. 1916. "Colorado Springs Folio, Colorado," U. S. Geol. Survey, Geol. Atlas, folio 203.—8, Sinclair, W. J., and Granger, Walter. 1914. "Paleocene Deposits of the San Juan Basin, New Mexico," Bull. Am. Mus. Nat. Hist., XXXIII, Art. 22. Bauer, C. M., and Reeside, J. B., Jr. 1920. "Coal in the middle and eastern parts of San Juan County, N. Mex.," U. S. Geol. Survey, Bull. No. 716 (g ).—9, Lawson, Andrew C. 1914. "San Francisco Folio, California," U. S. Geol. Survey, Geol. Atlas, folio 193.—10, Branner, J. C., Newsom, J. F., and Arnold, Ralph. 1909. "Santa Cruz Folio, California," U. S. Geol. Survey Geol. Atlas, folio 163.

Cretaceous Oshih and Ondai Sair gobi basins are almost certainly connected. Deposition must have begun in the Oshih earlier than in the Ondai Sair, since the Oshih beds are thicker, coarser and carry a fauna of rather more primitive aspect, and since the paper shales and large sauropods are found only in the upper beds of the Oshih, whereas they occur in the lower beds of the Ondai Sair. After deposition of the Oshih and Ondai Sair, sedimentation in this region ceased, or, if beds were deposited, they have been removed by erosion; but at Djadochta, forty miles east of Oshih, a gobi basin received 500 feet of early Cretaceous fine red sands probably derived from the destruction of Oshih beds. The next Mesozoic deposits of which we have knowledge are at Iren Dabasu, 380 miles farther east, where late Cretaceous beds rest directly upon pre-Cambrian slates. The locus of deposition had shifted, therefore, during Lower Cretaceous (Comanchean) and Cretaceous time.

Returning to the Altai and referring again to figure 16, the Gashato beds, which are the lowest Eocene strata we have seen, rest on the angular gravel which covers the Djadochta red sands (Fig. 11). The gap between the Djadochta and the Gashato represents the time recorded in the Iren Dabasu trachodont beds, plus an interval of Cretaceous and Paleocene or Eocene time that has left no sedimentary record so far as we now know. No younger formation was seen in this region, but both to the west and to the east there are later sediments. The Irdin Manha and the Shara Murun formations represent the highest Eocene yet found in Mongolia. They rest in some places upon the oldrock floor, but in other places they may lie upon Cretaceous or older Eocene sediments.

Thus, although we do not know the age of the Murukh Tchu or the Golobai, the facts demonstrate that there has been a shifting of the locus of deposition during the Eocene from the Altai region in earlier Eocene toward the Iren Tala in later Eocene time.

The oldest Oligocene beds yet seen in Mongolia are, apparently, those of Ardyn Obo, which rest directly upon the crystalline oldrock floor. The Oligocene of the Houldjin bench at Iren Dabasu should be rather younger, since it contains *Baluchitherium* bones. The *Baluchitherium* beds of Hsanda Gol have been called Lower Oligocene by Dr. Matthew.

Whether or not these three formations prove to be of the same age, the evidence of shifting of the locus of deposition is convincing. In at least three widely separated regions, warping recommenced in Lower Oligocene time, so that beds of this age were laid down, in one locality upon eroded Lower Cretaceous (Comanchean) beds, in the second upon the bare crystalline rocks, and in the third upon Eocene beds of doubtful correlation, somewhat older than the typical Irdin Manha (Fig. 16).

The only Miocene beds yet seen in Mongolia are those of Loh, which rest upon the Hsanda Gol without any notable appearance of a break in sedimentation. Thus far, this is similar to the findings in China where Dr. Andersson[1] refers a few beds to the "Lower Pliocene or Upper Miocene."[2]

This almost complete absence of the Miocene over vast areas of basin-lands constitutes one of the major problems of the region. Some of the elements of the problems are:

1. No marine Miocene beds are known in northern Asia, though Miocene lignites are reported as far north as the New Siberian Islands[3] hence the sea was remote and the Angara-Gobia continent was broad during that period.

2. The suggestion made by the patchy distribution of the earlier formations, as already recited in this paper, is that the deposits are all inland deposits. Despite the intermittent warping to form basins and receive sediments, therefore, the continent as a whole was stable and was undergoing removal rather than deposition of sediments.

This should imply either that we should find inland sediments of Miocene age more extensive than we have yet found, or that northern Asia was undergoing marked erosion during the Miocene.

The gaps in the record may represent periods of relative quiescence in which sediment was not being deposited, or was being eroded. If an upwarp was in progress, it is hard to see why a corresponding deposition should not be found as a record of it, unless the entire region was subject to erosion at the time. Such general erosion would be recorded in a peneplane, like that which beveled the Mesozoic beds prior to the deposition of the Tertiary. The preservation of vast areas of relatively thin, soft sediments, which represent many diverse horizons, and which are slightly or not at all disturbed, leads one to believe that the country was not greatly uplifted, and that it was suffering but little warping or denudation during the long intervals represented by the gaps in the sedimentary record.

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[1]Andersson, J. G. 1923. "Essays on the Cenozoic of Northern China," Table II. Mem. Geol. Surv. China, Ser. A, No. 3.

[2]A note recently published, entitled "Biological and Palæontological Collecting in Northern China," in the China Journal of Science and Arts, II, 1924, pp. 72–73, states, "The most recent expedition carried out by the two scientists [refering to Père Emile Licent and Père Teilhard de Chardin] resulted in the discovery in the valley of Shara Ossa Gol, a river in Mongolia to the north of Kansu, of a rich find of fossils and archæological specimens in deposits running in a complete series from the Miocene of the Upper Tertiary to recent strata of Neolithic age."

[3]Toll, Baron E. W. 1900. "Carte géologique du Nord de la Sibérie Orientale," reproduced in Petermann's geographische Mitteilungen, XLVI, Pl. xiii, quoted from Suess, 1902. "La Face de la Terre." III, 1, p. 29.

It seems to follow, independently of the inferences just offered, that the weight of the sediment could have had no causal relation to the depression of the earth's crust. The fact that areas as large as 10,000 square miles in extent are floored by thin formations, as in the case of the Irdin Manha-Shara Murun basin, seems to indicate that these beds were laid down upon a relatively flat surface that did not tend to sink under the load. The crust evidently supported these and other formations while they were peneplaned. The peneplanations are taken to imply great stability and rigidity of the bedrock floor,—that is, the crust neither sank under the load sufficiently to deform the sediments and encourage thicker deposits, nor rose under the negative load, when the region was eroded to a peneplane. In a paper to be offered later, a review of the diastrophic periods in Mongolia will be attempted, but at present it is enough to say that we believe that isostatic balance can be overset only by very large positive and negative loads, and that the stripping and loading observed in Mongolia have been of an order of magnitude too small to overcome the inertia of the earth's crust, even where fault lines exist. In the dynamics of the region, the sediments played a passive part. Basin-warping and mountain-building were complementary parts of a great orogenic movement or succession of movements, and were controlled, we believe, by deep-seated causes.