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THE PENEPLANES OF MONGOLIA¹

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This paper is another of the brief announcements that have been issued from time to time by the geologists of the Third Asiatic Expedition. A larger chapter on the Physiography of Mongolia is in preparation; but, as references are being made in other connections to the "Gobi Peneplane," the "Mongolian Peneplane," etc., it seems desirable at this time to define these baselevel surfaces, even though adequate discussion,

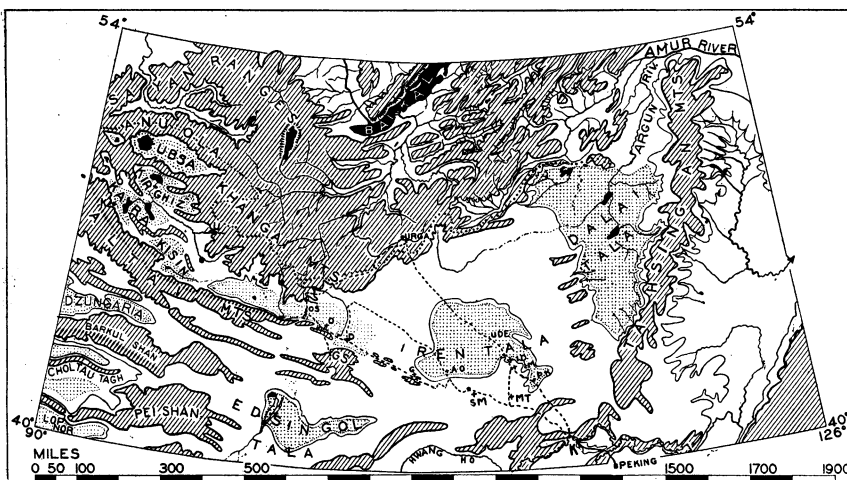


Fig. 1. Generalized map of Mongolia.

Mountainous areas are shaded in slanting lines. Lowlands are white, and the deeper depressions are stippled. The Arctic divide is shown by a line of round dots. The routes of the Expedition are shown by heavy broken lines. Index letters along the route of the Expedition indicate the following places mentioned in the text: K (northwest of Peking), Kalgan; PK, P'ang Kiang; IM, Irdin Manha; AO, Ardyn Obo; OS, Ondai Sair. Sain Noin Khan is in the Khangai Mountains, on a river that lies south of the Arctic divide, about midway between the Ondai Sair and M of Mts. Uskuk Mountain, not shown on this map, is just west of Ondai Sair.

especially of the problems of their mode of origin, must await the publication of the larger report.

THE MONGOLIAN PENEPLANE.—A clearly defined ancient erosion surface bevels all the mountainous areas of Mongolia. Remnants of an

¹Publications of the Asiatic Expeditions of The American Museum of Natural History. Contribution, No. 30. 31

older unreduced upland rise above it as monadnocks, and the valleys carved out below the peneplane represent so mature a dissection that by far the major part of the old erosion plane has been destroyed. Provisionally, this old surface of mature erosion has been called the Mongolian peneplane, because of its very widespread distribution in Mongolia (Fig. 2).



Fig. 2. The maturely dissected Mongolian peneplane in southern Mongolia, on the Kalgan-Urga trail.

The picture is drawn from a panoramic photograph, taken at the upland level, looking south and southwest.

It is possible that this peneplane is the surface which passes underneath the Cretaceous sediments, which undoubtedly rest upon a mature surface of erosion.¹ This matter will be discussed in another paragraph.

The peneplane was first observed in the granite mountains of southern Mongolia, at an altitude of 5,300 feet (1,600 meters). But as we climbed toward the Arctic divide, at about 6,000 feet (1,830 meters) south of Urga, an old mature surface was again seen beveling the schists

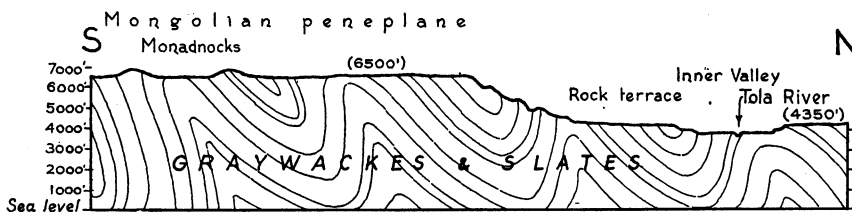


Fig. 3. Diagrammatic section across the Tola River at Urga.

The figure shows: (1) monadnocks rising above the peneplane; (2) the peneplane; (3) the broad rock terrace; (4) the inner valley cut below the rock terrace.

and the younger graywackes. Northwestward, other higher ranges could be seen, and probably the faulted ranges of Transbaikalia are beveled by a peneplane, which in the faulting has been lifted to unequal heights and tilted at somewhat unlike angles in the several fault blocks.

At the Tola River, near Urga, the following topographic elements were observed: (1) monadnocks rising above the peneplane; (2) the

¹Berkey, C. P., and Morris, F. K. 1924. "Basin Structures in Mongolia." *Bull. Amer. Mus. Nat. Hist.*, LI, p. 109.

peneplane; (3) a broad rock shelf or terrace within the valleys of the Tola and its tributaries; (4) an inner valley, sunk gorgelike below the rock terrace yet having a mature floor upon which the river meanders. These relations are graphically expressed in figure 3.

THE KHANGAI PENEPLANE.—When we climbed into the Khangai Mountains north of the great lamasery of Sain Noin Khan, we saw again an ancient mature upland, carved by streams and, in the highest parts,



Fig. 4. Distant view of the Khangai peneplane.

The figure is part of a large field sketch made near Sain Noin Khan, looking northward over two intervening mountain ridges to the Arctic divide, which forms the skyline. The peneplane is a broad, gently rolling surface, above which rise low monadnocks. Several glacial cirques are seen, but the glaciation was not severe.

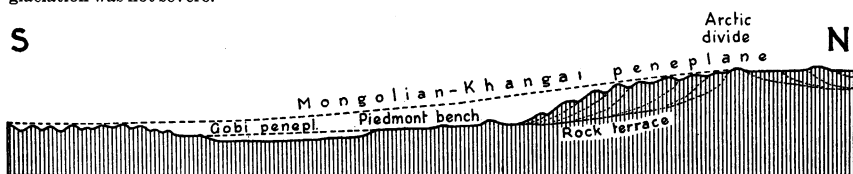


Fig. 5. Diagram showing the Khangai peneplane at the north, warped downward so as to form the Mongolian peneplane in the south.

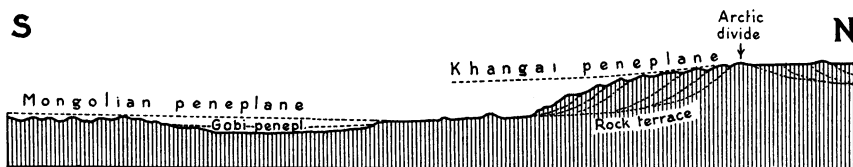


Fig. 6. Diagram showing the Khangai peneplane as an independent, older surface than the Mongolian peneplane.

by former glaciers. Above this peneplane rise notable monadnocks. The physiographic unconformity between the valleys and the ancient upland surface is very clearly seen in this region (Fig. 4). We were not wholly sure of the identity of this upland with the Mongolian peneplane, and so called it provisionally the Khangai peneplane. It stands at about 10,000 feet (3,000 meters), at the place where we observed it, and so should be older than the Mongolian peneplane, unless these two erosion surfaces

can be shown to be identical. There is a shoulder or high rock terrace bordering the valleys.

Descending from the Khangai Mountains and coming southward, we followed the peneplane as carefully as possible, to test its relations with the Mongolian peneplane. The valleys broaden southward, and the rock benches within the valleys tend to coalesce, so that remnant hills or outliers of the Khangai Mountains are cut off from the long spurs and lie

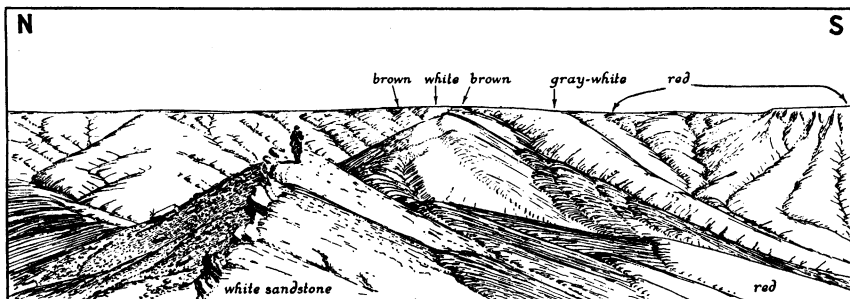


Fig. 7. Field sketch showing the dissected Gobi peneplane at a point about 30 miles north of Baga Bogdo.

The skyline represents the peneplane beveling upturned Tertiary sediments. The upland is extraordinarily smooth, but in the badlands formed by dissection of the Gobi peneplane, the tilted beds develop varying topographic expression, according to their hardness. Many of the gullies have asymmetrical cross section, the southward sloping wall being the longer. A lens of cemented white sandstone forms a small hogback, near the center of the foreground.



Fig. 8. Field sketch of the Gobi peneplane at Ardyn Obo, looking eastward.

The sketch shows: (1) the remarkably level surface of the Gobi peneplane, beveling strata that are sensibly horizontal; (2) the lowland of the P'ang Kiang stage at the left; (3) the badland bluffs descending about 300 feet from the Gobi upland to the P'ang Kiang level; (4) the remarkable shortness of the gullies of the dissected zone, in contrast to the great area of the P'ang Kiang lowland (see figure 11).

isolated, surrounded by the erosion lowland. Looking southward from such border fringes of the Khangai hills, it seemed that the new, lower beveling continues southward over the tops of the ranges there. Lacking adequate maps or surveys, it is very difficult to be wholly sure of such a correlation; but if our observation was not at fault, it would support the inference that there are two peneplane levels beveling the hard-rock structures of Mongolia: an older baselevel, the Khangai peneplane, and the younger and lower Mongolian peneplane (Fig. 6). This matter will be discussed more fully in a later paragraph of this paper.

THE GOBI PENEPLANE.—At altitudes lower than the Mongolian peneplane, we observed a surface of extraordinary smoothness developed upon the relatively soft basin sediments. It is a peneplane, not a deposition surface, as shown by the following considerations: (1) it bevels tilted and faulted strata; this was notably observed in the Altai piedmont regions at Eastern Badlands (Fig. 7); (2) it is underlain by sediments of widely different age; for example, by the Eocene rocks at Irdin Manha, and by the Oligocene sediments of Houldjin, less than 10 miles north of Irdin Manha; (3) even where the strata were sensibly horizontal (Fig. 8), the plateau upland cannot be a depositional surface, for it is impossible that surfaces of Eocene, Oligocene and Pliocene deposition should to-day all be in the same stage of incipient dissection.

It seems to us to be demonstrated that the Gobi upland surface is indeed a baselevel of erosion, or true peneplane; but whether it is of æolian origin or is the work of water in a past cycle of more humid conditions, is one of the most difficult and unsettled problems of the region.

THE P'ANG KIANG LOWLAND.—The Gobi peneplane is interrupted by innumerable undrained hollows, which range in size from about 200 yards to tens of miles in length, and from 20 feet to 400 feet deep. The larger hollows have relatively flat floors, though they are never so perfectly level as the Gobi upland, and in almost all cases contain several shallow playas. Because the important telegraph station at P'ang Kiang lies in a large hollow of this type, we have assigned all these hollows to the "P'ang Kiang stage" of dissection (Fig. 8).

We have thus four levels to consider—the Khangai, the Mongolian, the Gobi and the P'ang Kiang levels. At least three of these levels are clearly separate, but it is not certain that all four are separate or are of wholly different age. The brief space allotted to this paper permits us to do little more than state the problems.

RELATIONS OF THE KHANGAI AND MONGOLIAN PENEPLANES.—The question of the possible identity of the Khangai and Mongolian peneplanes is given graphically in the diagrams, figures 5 and 6.

In figure 5 the significant events may be summarized as follows: (1) there was a folded and complex mountainous oldland; (2) this mountainous country was peneplaned,—leaving residual monadnocks; (3) the peneplane was warped and locally faulted, especially in the Altai and Zabaikal regions, and was deeply dissected. In the Khangai Mountains the uplift was a very broad, gently sloped anticlinal warp, which was much higher than some of the other upward areas farther south.

Figure 6 records the following stages: (1) there was a complex and folded mountainous oldland; (2) this oldland was reduced to a baselevel or peneplane, above which stood low residual elevations or monadnocks: this is the Khangai peneplane; (3) the region was uplifted; (4) it was then subjected to erosion so prolonged that the Khangai peneplane was wholly destroyed over a broad area, and a new baselevel was achieved, south of the Khangai region. This is the Mongolian peneplane, above which the Khangai is itself a monadnock unit.

The crux of this problem lies in the question of the age of the Mongolian peneplane. The oldest basin sediments are of late Mesozoic, probably Lower Cretaceous age. They rest upon a peneplane which has been carved upon the oldrocks since the last mountain-folding. If this folding took place, as we believe, in Middle Jurassic time, these mountains must have been reduced virtually to baselevel by the beginning of the Lower Cretaceous (Comanchean). It seems very improbable that two major peneplanes, the Khangai and the Mongolian, could

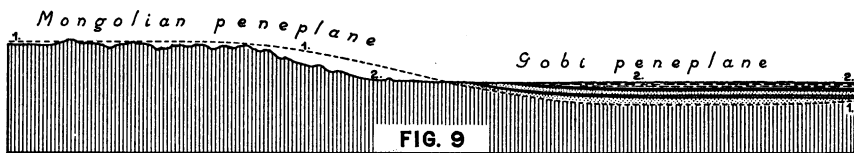


Fig. 9. Diagram illustrating the thesis that the warped Mongolian peneplane is the surface upon which the basin sediments rest.

have been developed in this interval. If then the Mongolian peneplane is the surface on which the oldest Gobi sediments rest (Fig. 9), we should consider this an argument in favor of regarding the Khangai and Mongolian peneplanes as one and the same warped surface. But if the Mongolian be a much younger surface than the pre-Cretaceous peneplane, as suggested in figure 10, the question of the identity of the Khangai and Mongolian peneplanes would be reopened. Even in that case, the following considerations are opposed to their being two separate stages: (1) the Mongolian peneplane is as elaborately dissected as is the Khangai upland; if it were so much younger, it should be less dissected; (2) it can be shown that very much warping and faulting have taken place in Mongolia, so that an old upland peneplane might be expected to lie at very different levels in different parts of the country; (3) it seems to us that it is not logical to expect a great upland peneplane like the Khangai to survive the removal of the enormous quantities of hard rock, together with the long period of very slow decay and removal that must

come in the later stages of post-mature dissection, involved in the carving of a new peneplane, several thousand feet lower than the Khangai, over a large part of Mongolia.

At first sight, this interpretation might seem comparable to the conclusions of Marius R. Campbell¹ in the Front Range, where he finds the Flat Top peneplane as an older, and the Rocky Mountain peneplane as a younger and lower level, both beveling the same hard rocks. But the Flat Top peneplane is almost wholly destroyed by erosion, while the Rocky Mountain level is the most striking and widespread landform of the Front Range; this contrast in degree of dissection and destruction of the two peneplanes seems to be lacking in the case of the Khangai and Mongolian peneplanes. It would be stretching Dr. Campbell's interpretation beyond reason, we think, to cite it as a case quite parallel to that of the Khangai and Mongolian peneplanes. A further discussion of the problem involves the relation of the Mongolian to the Gobi peneplanes.

RELATIONS OF THE GOBI AND MONGOLIAN PENEPLANES.—The Mongolian peneplane always lies higher than the Gobi peneplane that bevels the basin-sediments. There is no doubt that the Mongolian base-level is much the older of the two. The questions to be solved are the following: Is the surface that underlies the gobi basins the downwarped Mongolian peneplane (Fig. 9)? If not, at what date was the Mongolian peneplane completed?

In some instances the peneplane now exposed in the field can be shown to be a morvan, that is, a once-buried peneplane which has been laid bare by the stripping of the sediments which formerly covered it. This is the case in the peneplane at Uskuk Mountain, where early Tertiary sediments, and possibly Cretaceous beds as well, once covered what is now the top of the mountain block.²

It is a possible interpretation, therefore, that the Mongolian peneplane is the surface upon which the earliest basin sediments were laid down, and this was indeed the theory with which we at first worked in the field.

As we obtained increasing evidence of the widely different periods of basin-warping, however, it was judged that the entire history was more complex than it seemed at first. The following considerations are some of the elements of the problem: Buried peneplanes or unconformities and disconformities are numerous and imply long gaps in the sedimentary

¹Campbell, M. R. 1922. "The Peneplanes of the Rocky Mountain Region." U. S. Geol. Survey, Bull. No. 730.

²Berkey, C. P., and Morris, F. K. 1924. "Basin Structures in Mongolia." Bull. Amer. Mus. Nat. Hist., LI, p. 114, Fig. 10.

record. Thus in the Altai region the section includes: (1) early Lower Cretaceous shales and sands, disturbed by tilting and faulting; (2) early Tertiary conglomerates, sands and clays, whose upper beds carry a Lower Oligocene fauna; (3) Lower Miocene clays, and (4) Upper Pliocene sands and gravels. Clearly there are gaps in the sedimentary record, and at least two of these gaps represent peneplanations—one at the base of the Cretaceous, and the other at the base of the Tertiary, when the faulted and tilted Mesozoic rocks were reduced to baselevel.

The relatively thin fills of sediment, deposited at great intervals of time, seem to indicate that during each of these long periods in which no deposit was made, erosion might well have baseleveled the very moderately uplifted land from which the preceding sedimentary fill had been

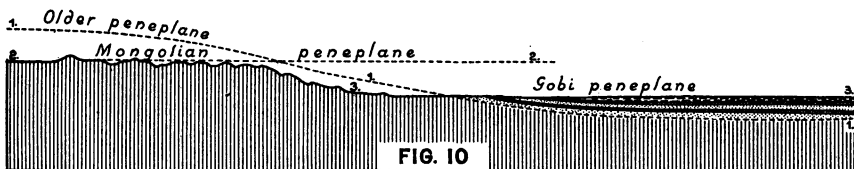


Fig. 10. Diagram illustrating the thesis that the basin sediments rest upon an older surface than the Mongolian peneplane.

The stages of development indicated in this diagram are: (1) an ancient peneplane, probably pre-Cretaceous. This was warped to form basins, and sediments were deposited in these basins; (2) the warped region was peneplaned, forming the Mongolian peneplane; (3) a new level surface, the Gobi peneplane, was beveled across the soft rocks of the basins, and, to some extent, the upstanding hard-rock masses have been girdled by a rock bench which is continuous with the Gobi peneplane.

washed. It seems to us that, in a region where one alternation of slight warping and quiescence followed another all through the late Mesozoic and Tertiary, a peneplane like the Mongolian might be made *paripassu* with the deposition of sediment. Hence, the Mongolian peneplane may not be of pre-Cretaceous age, but may have been finished at a much later time, say in the Middle Tertiary, and may have been finished at different times in different parts of the country.

The absence of Miocene sediments over most of the region studied by the Expedition¹ and over all or nearly all of Northern China² as well, rather suggests the Miocene as a period of very widespread erosion, in which the closing stages of peneplanation were completed. The great post-Oligocene disconformity, which is very striking everywhere except at the Hsanda Gol, where the break between beds of Lower Oligocene and

¹Berkey, C. P., and Morris, F. K., *loc. cit.*, p. 126.

²Andersson, J. G. 1923. "Essays on the Cenozoic of Northern China." Mem. Geol. Surv. China, Ser. A, No. 3.

those of Lower Miocene age is inconspicuous, may correspond to the Mongolian peneplane developed on the hard rocks.

Summarizing these relations, it seems possible that the Mongolian peneplane may prove to be the surface upon which the oldest Lower Cretaceous sediments were laid down (Fig. 9); but if so, it could not be the surface upon which were deposited such sediments as the Ardyn Obo formation (Oligocene) and the P'ang Kiang formation (Miocene or later). But it seems more likely to us that the pre-Cretaceous peneplane has been destroyed everywhere, except (1) where it is still covered by basin sediments (Fig. 10), or (2) where it has been re-exposed, in comparatively recent time, by the removal of its sediments. In this case the Mongolian peneplane would be much younger than the pre-Cretaceous, and might have been completed in Tertiary time, perhaps in the Miocene.

The conditions under which the Gobi peneplane was formed, and the date of its completion are questions of some difficulty. Since late Pliocene beds are beveled by this surface at Hung Kureh, the peneplane must have been formed during the Pleistocene. Its recency is also attested by its extraordinarily smooth surface, undissected save for the hollows that represent the P'ang Kiang stage of erosion. Part of the difficulty lies in the question, how such widespread peneplanation could have been accomplished in a region as uplifted as the interior of Asia must have been during the Pleistocene, which was undoubtedly a period of mountain growth. East of Uskuk Mountain in the piedmont region north of the Altai, the Gobi peneplane is domed or arched, and is carved into an intricate network of gullies that in some places are well-developed badlands. Clearly the Gobi peneplane is here being destroyed, not formed, at the present time. The fresh badland bluffs bordering the P'ang Kiang lowlands in so many parts of Mongolia show that everywhere the Gobi peneplane is being destroyed rather than made in the present cycle, and that both wind and running water are agents of its destruction.

RELATION BETWEEN THE GOBI PENEPLANE AND THE LOWLANDS OF THE P'ANG KIANG STAGE.—As there is no doubt that the P'ang Kiang hollows are younger than the Gobi peneplane, the only problem is their mode of origin. A paper on this subject will be offered shortly, and it must suffice here to give only a brief description.

The hollows never were the beds of large lakes, though small shallow playa basins lie scattered on their broad floors. There is commonly a shelf or terrace in the hollow, but no sign of beaches, bars, wave-cut cliffs or delta terraces that might indicate the former presence of large lakes. The bluffs that form the descent from Gobi upland to P'ang Kiang

floor may be fairly smooth, or may be carved into badlands by innumerable short gullies, and these two contrasting conditions may be present on the same bluff within a few miles. We believe that the hollows are the result of the combined action of wind and running water. According to this view, the first stage of development was a deflation hollow, or blow-out, made by the wind. But when it became deep enough to reach moisture that might encourage vegetation, the rate of deepening by wind was decreased, while erosion of the surrounding bluffs that walled in the hollow was carried on, intermittently, in the rainier seasons, by short

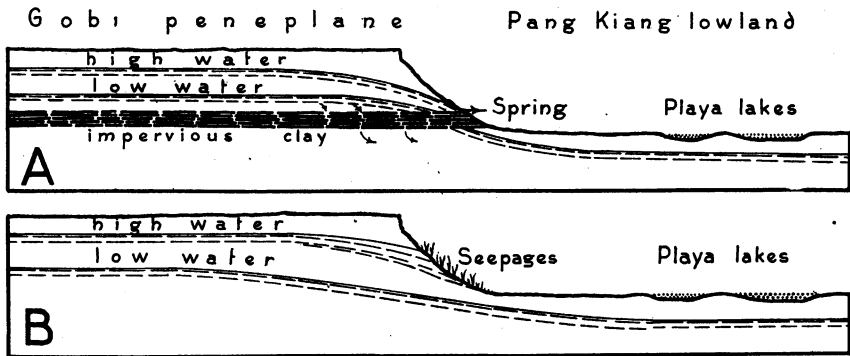


Fig. 11. Two diagrams illustrating the distribution of ground water in the sediment basins.

The vast gravelly surface of the Gobi peneplane absorbs water readily into the porous sediments. In time of high groundwater level, a series of springs or seepages, or both, appears at the cliff front to reinforce whatever rainwash there is. Thus a series of short, steep gullies is developed, as shown in figure 8. The sediment washed out of these gullies is spread over the bottom of the hollow and, when dried, is largely carried away by the wind.

streams supported by springs and seepages. The vast area of the Gobi upland, with its gravel surface, readily absorbs the rain and melting snow, while the broad shallow fill of porous sediments acts as a reservoir of groundwater. When seasons of exceptional rainfall raise the water-table, dissection of the cliff-front becomes active through the escape of spring waters (Fig. 11). The washed-out material is spread in thin sheets upon the floor of the hollow, where, through the long dry season, it is subject to the work of powerful winds. The upland near the hollows, especially on the southern and eastern sides, is in many instances covered with sheets of dune sand. We believe that water is the chief agent of erosion of the cliff, while wind is the chief agent of complete removal of loose material from the floor of the hollows.

COMPARISON WITH OTHER REGIONS.—As yet, data are not available to us to show whether the Russian geologists have published papers

dealing with the peneplanes of the northern country. In China, the classic work of Bailey Willis¹ and the more recent studies by Andersson² offer means of comparison, though as yet it is too early to seek an actual correlation in physiographic stages. We offer for brevity's sake the stages recognized by Bailey Willis as revised in part by Andersson:

1. The Pei T'ai stage.—Early Tertiary—"We take this broad flat form to represent a stage of erosion to advanced old age, the nearest approximation to a peneplain which we have found in the course of our journey."³

2. "T'ang Hsien stage (Pliocene).—Deposition of gravels and clays with the Hipparion fauna. Landforms of advanced maturity.

3. "Fen Ho stage (Early Pleistocene).—Earth movements and subsequent revival of vertical erosion.

4. "Ma Lan stage (Middle Pleistocene).—Cold arid climate. Deposition of valley gravels and æolian loess with *Elephas* sp.

5. "Pan Chiao stage (Late Pleistocene).—Climate semiarid, abundant summer rains. Dissection of the valley gravels and primary loess. Formation of redeposited gravels and loess, with *Bos* sp., *Ovis* sp. and *Cervus* sp."⁴

These may tentatively be compared with the stages recognized in Mongolia, as follows, placing the oldest stages at the bottom of the column:

China	Mongolia
8 Modern dissection	Modern dissection
7 Pan Chiao dissection	P'ang Kiang dissection
6 Ma Lan, loess stage	Gobi peneplane
5 San Men, ⁵ pluvial epoch (valley gravels)	
4 Fen Ho uplift	Warping and uplift
3 T'ang Hsien, partial peneplanation	Rock terraces
2 Pei T'ai peneplane	Mongolian peneplane
	Khangai peneplane ?
1 Monadnocks	Monadnocks

ADDENDUM

After this paper had been sent to press, the authors read V. A. Obruchev's essay "The Gateway to China,"⁶ in which the great Russian geologist describes a very perfect upland peneplane beveling the mountains of western Dzungaria. Several photographs of this ancient surface are figured.

¹Willis, Bailey, Blackwelder, Eliot, and Sargent, R. H. 1907. "Research in China." Carnegie Instn. Wash., Pub. 54.

²Andersson, J. G. 1920, quoted by Yih, L. F. 1920. "Geology of the Western Hills of Peking." Mem. Geol. Surv. China, I, pp. 65-77.

³Willis, B., *loc. cit.*, p. 237, and Pls. xxxii, xxxiii, xxxv and Atlas sheet E I.

⁴Andersson, J. G. 1920, quoted by Yih, L. F. 1920. "Geology of the Western Hills of Peking." Mem. Geol. Surv. China, I, p. 74.

⁵Ting, V. K. 1923, quoted by Andersson, J. G. 1923. "Essays on the Cenozoic of Northern China." Mem. Geol. Surv. China, Ser. A, No. 3, p. 117.

⁶Obruchev, V. A. 1915. "Votora v Kitai. Geographicheski i geologicheski ocherk pograničnoi Dzungari." ("The Gateway to China. Geographical and geological sketch of the boundary of Dzungaria). Izvestia Imp. Russ. Geogr. Soc., LI, No. 5, pp. 277-322, with tectonic map and 5 plates. (St. Petersburg.)

