A BRIEF SUMMARY OF THE TERTIARY FORMATIONS OF INNER MONGOLIA AND THEIR CORRELATION WITH EUROPE AND NORTH AMERICA.

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INTRODUCTION

Before the Central Asiatic Expeditions was sent into Mongolia by the American Museum of Natural History in New York, the geology and palæontology of that enormous territory remained quite unknown to the scientific world. In the year 1922 the first expedition was organized and then in the following years 1923, 1925, 1928 and the last one* in 1930. Through those expeditions, this interesting enormous land of Mongolia became very famous to the scientific world. Not only the geology of Mongolia, but also the numerous, valuable palæontological collections have aroused the greatest interest. In no other place in the world than Mongolia are the Tertiary formations so widely distributed or so completely represented (from Basal Eocene to Pliocene); and in no other known locality are those formations so little disturbed. The Tertiary formations in Mongolia and even the Cretaceous beds suffered very little disturbances, and they lie almost horizontally. Sometimes the beds are warped or tilted a little, but these are only local disturbances. Strong folding of the strata never occured.

All the sediments from Cretaceous to Pliocene are of continental origin, either of lake or river deposits, ice in river channels, or on flood planes. Eolian deposits are also sometimes represented. Owing to the slight deformation of the strata the palæontological contents are mostly in a wonderful state of preservation. Moreover, many of the species are new not only for Asia but for other continents as well. These faunas fill an important gap and help to link more closely the European and American faunal world. The difficult problems of mammalian centres of evolution and migration will also be brought nearer solution when all the materials have been thoroughly studied.

* The author took part to the last expedition organized as a Sino-American joint enterprise, through the courtesy of the American Museum and the American leader of the Expedition, Dr Chapman Andrews.

The Tertiary Stratigraphy

Under this heading I shall try to give a brief summary of the Tertiary formations of Inner Mongolia which are encountered in the last expedition in 1930.

The Lower Tertiary formations are very well developed on the west side of the Kalgan—Urga trail. The Palæocene deposits are however not known in the districts visited. So far as I know, only one Palæocene formation, the so called Gashato[1] Formation, which directly overlies the Cretaceous Djadokhta beds at the foot of Gurbun Saikhan range in Outer Mongolia, could be assigned to this period. This formation is characterized by the diagnostic vertebrate groups of *Notoungulata, Multituberculata* and *Creodonta*. These are all mammals of archaic types. According to W. D. Matthew, W. Granger and G. G. Simpson, this formation can be correlated with the Cernaician formation of Europe and the Fort union of North America.

Both the Eocene and Oligocene formations are widely distributed along the Irlian—Ulan-Hwa trail and especially in the south western part of it. The Eocene sediments consist of sands, clays and sometimes of calcareous sands and marls. The thickness of the beds varies a great deal in different places. At the Margett's camp 5 miles north east from Duhum Usu, the Eocene beds are rather thin; they reach a thickness of only about 20 meters, but in a locality 3 miles west of Duhum Usu, they are about 70 meters thick. Where the Eocene beds is exposed, it lies unconformably upon the Cretaceous beds. Upon the Eocene beds lie disconformably the Oligocene formations. Whereever the Oligocene sediments were removed by erosion, the Eocene formations are exposed at the surface.

Eocene Period

The Eocene formations of different localities can be divided into four horizons in descending order as follows.

4. Shara Murun formation
3. Irdin Manha formation
2. Arshanto formation
1. Duhum formation

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1 Matthew, W. D. Granger, W., and Simpson, G. G. 1929 Amer. Mus. Novitates, No. 376.

THE DUHUM FORMATION

During the field season of 1930, the Central Asiatic Expedition spent about 7 weeks in the Duhum Usu district, which lies along the trail from Irlian (Iren Dabasu) to Ulan-Hwa. Duhum Usu is the name of a well lying about 30 miles south west of Irlian. In 1928 this region was only crossed by the expedition but in the last year we had a good opportunity to study the geology of the district and to collect fossils.

Of the many formations of the Eocene Period which had been visited by our field party, only this one had not been known from the previous expeditions. It is of great stratigraphic importance, and I propose to call it the "Duhum formation", after the name of that well Duhum Usu.

The Duhum formation is the lowest formation of the Eocene Period known in Mongolia (except the Gashato formation in Outer Mongolia). It is very well developed in this district and the fossils are both abundant and well preserved. The diagnostic fossil mammal of this formation is the Genus *Coryphodon*. The skull of this animal is very long and narrow, but the molars are very similar to those of the genus *Bathyopsis* from the Wind-River Beds of Wyoming in North America. It seems to me that the premolars of the coryphodonts are much more primitive and smaller than those of *Udinoceras*,[1] obtained from the Irdin Manha beds. *Protitanotherium*, which is characteristic of the Irdin Manha formation, is totally wanting at this horizon. Judging from the stratigraphic relation as well as from the faunal content, the age of the Duhum formation will be provisionally assigned as Lower Eocene or the lower part of Middle Eocene. It is probably still lower than Arshanto formation. I shall discuss it more in detail with illustration of several sections.

I. Section at 2 miles west of Duhum Usu (7 miles S. W. from Margett's Camp).

The succession of the strata in descending order is as follow:

5.	Series of arkosic sandstones and gravel beds	4	meters
4.	Series of white fine sands	4	,,
3.	Red clay beds almost barren.....	2	,,

1 Osborn, H. F. 1924, Amer. Mus. Novitates, No. 145.

2. A series of greenish coarse sandstones..... 1½ ,,

1. Red clay beds with sandstone lenses and intercalations..... 20-30 ,,

1. The lowest beds are composed mainly of red clays with sandstone intercalations or lenses. These beds may at certain places reach a thickness of about 30 meters. The small perisodactyles are the most common fossils at this horizon. The teeth and foot bone fragments of this animal are scattered every where in these beds.

2. This series consist of greenish and yellowish coarse sandstones which are only two to five feet thick. The very long and narrow skulled *Coryphodon*

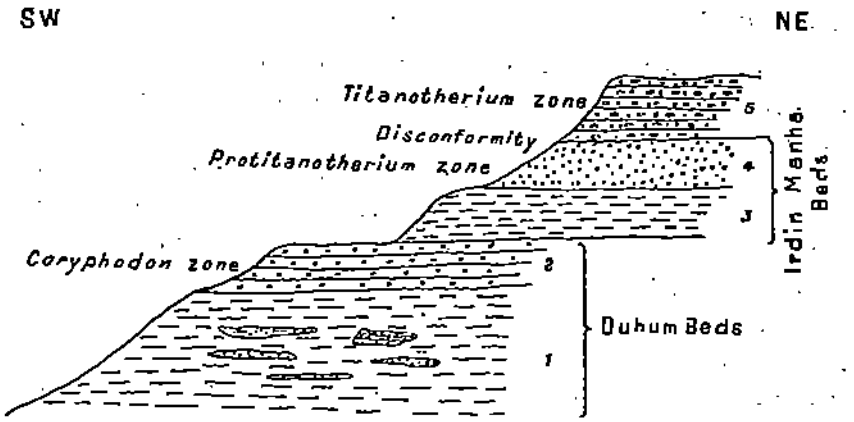

Fig. 1. Section at 2 Miles west of Duhum Usu (7 Miles S. W. from Margett's Camp)
1. Red clay beds with sandstone intercalations 2. A series of greenish coarse sandstones 3. Rey clay beds almost barren 4. Series of white fine sands 5. Series of arkostic sandstones and gravels

is the diagnostic fossil of this horizon. Except the *Coryphodon*, *Lophialetes* are the most common forms.

3. Red clay beds:—This horizon may be tentatively correlated with the Arshanto beds.

4. Series of white fine sands: This is the upper part of the Eocene beds in Duhum Usu district. The Genus *Protitanotherium* is the diagnostic fossil of this horizon. The small Perisodactyles are also very common. According to the faunal content, these beds are without doubt the equivalent of the Irdin Manha formation.

5. Series of arkosic sandstones and gravel beds: Upon the fine sands just mentioned lies disconformably a series of arkosic sandstones and gravels. They are usually gray, greenish or yellowish in color. *Titanotherium* is the characteristic fossil of this horizon. *Baluchitherium*, the giant hornless rhinoceros is wanting. Judging from the faunal content, these beds belong very probably to Middle Oligocene.

II. Section near the Margett's Camp, 5 miles northeast from Duhum Usu.

The succession of the strata in the neighbourhood of the Margett's Camp shown in figure 2 is about the same as the section which we have just described. For the sake of comparison the different strata will be enumerated below:

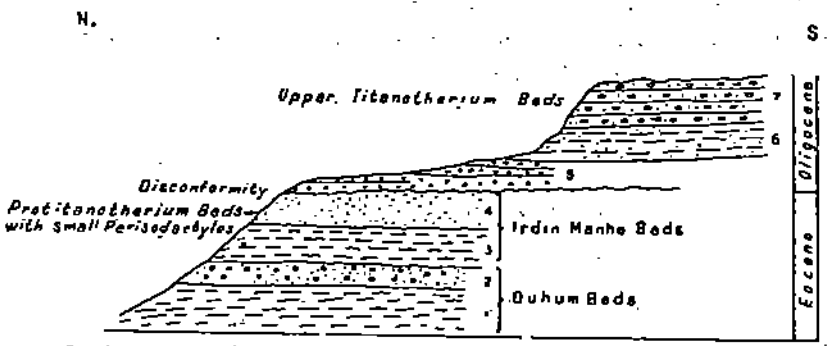

Fig. 2. Section near the Margett's Camp, 5 Miles north east from Duhum Usu
1. Red clays 2. Yellowish and greenish coarse sands 3. Red clay 4. White fine sands 5. Yellowish and greenish gravels 6. White calcareous sands 7. Compact arkostic sandstones

The Oligocene beds

7.	Compact arkosic sandstones	2—4	meters
6.	White calcareous sands	1	,,
5.	Yellowish and greenish gravels	1½	,,

The Eocene beds

4.	White fine sands	4	,,
3.	Red Clay	1—3	,,
2.	Yellowish and greenish coarse sands	1	,,
1.	Red clays	8—12	,,

THE ARSHANTO FORMATION[1]

This formation was first studied by the American geologists in the Arshanto district, about 12 miles west from Gur Tung Khara Usu. It consists prevailingly of red clays of hard character. The clay is usually structureless and probably it was deposited by wind. Only tooth fragments of small lophiodonts have been collected from this formation. The thickness of these beds is only about 5 meters or a little less.

THE IRDIN MANHA FORMATION

This formation is well developed in the Irdin Manha district. It consists mainly of red, brown, and gray clays and sometimes white fine sands. Its thickness varies from 12 to more than 34 meters. This formation is succeeded disconformably by Oligocene beds. The fauna of these beds is exceedingly rich. The most important mammals, described by the American palæontologists are the following:

Perisodactyla

Helaletidae?

Desmatotherium mongoliense Osborn

Lophiodontidæ

Lophialetes expeditus Matthew & Granger

Lophialetes minutus Matthew & Granger

Titanotheriidæ

Protitanotherium grangeri Osborn

Dolichorhinus olseni Osborn

Telmatherium berkeyi Osborn

Artiodactyla

Helohyidæ

Gobiohyus (2 species)

Amblypoda

1 Publications of the Asiatic Expeditions of the Amer. Mus. of Nat. Hist. Contribution No. 64

Eudinoceras mongoliense Osborn

Carnivora

Mesonychidæ

Andrewsarchus mongoliensis Osborn

Hapalodectes servus Matthew & Granger

Hyaenodontidæ

Hyaenodon irdinensis Matthew & Granger

Propterodon irdinensis Matthew & Granger

Miacidæ

Miacis invictus Matthew & Granger.

THE SHARA MURUN FORMATION

The Shara Murun beds are well represented in the Shara Murun district, from which it derived its name. They consist chiefly of white sands and gray clays, generally in alternation. Bones are abundant and in general well preserved in the gray clay. Most genera of the mammalian fossils from these beds occur also in the Irdin Manha formation; but the specific character of the fauna from the Shara Murun beds are of more advanced type than those from the Irdin Manha beds. For this reason, the Shara Murun formation has been regarded as uppermost Eocene.

Besides those formations of the Eocene period mentioned before, there is still one formation, the Tukhum formation described by the American geologists. It underlies the Shara Murun beds. No diagnostic fossils have been collected from these beds. Judging from the stratigraphic relation, the Tukhum formation may be equivalent to the Irdin Manha formation or a part of it.

Based partly on the stratigraphic relations and partly on the researches of the American palæontologists, a table of correlation of the Eocene formations in Mongolia with those in Europe and North America will be shown as follows:

Table of Correlation

The Eocene Formations and the Correlations

		Mongolia		Europe	N. America
Eocene		Formations	Life Zone		
	Upper E.	Shara Murun	Protitanotherium	Ludian	Uinta C
	M.E.	Irdin Manha	Protitanotherium	Ludian	Uinta B & C
	L. E.	Arshanto	Primitive Lophiodonts	Bartonian ?	Uinta A ?
		Duhum	Coryphodon	Sparnacian L. Ypresian	Wasatch
	B. E.	Gashato	Palæostylops	Cernaisian	Fort Union

OLIGOCENE PERIOD

The distribution of the Oligocene beds in Inner Mongolia is the same as the Eocene beds, restricted mainly on the west side of the Kalgan-Urga trail and along the Irlian=Ulan-Hwa trail. At certain places, where the Oligocene beds are entirely eroded away, the Eocene beds are exposed on the surface; where both beds are present, the Oligocene beds lie disconformably upon the Eocene. The Oligocene sediments are much better developed in the south western part of the Irlian=Ulan-Hwa trail and become thinner and thinner along the north eastern part. In Margett's Camp district, only two to six meters of Oligocene beds are represented.

The Oligocene formations encountered by the last expedition in 1930 are the following:

3. Baron Sog formation
2. Houldjin formation
1. Ulan Gochu formation

The Ulan Gochu[1] beds consist chiefly of deep red or pinkish clays and gray or white sands. The clays and sands occur generally in alternation. The thickness of the formation varies from 42 to 65 meters. The diagnostic

1 Berkey, C. P., Granger, W., and Morris, F. K., 1929, Amer. Mus. Novitates, No. 385.

mammal fossils are the battle-ram-nosed rhinoceros, known as *Embolotherium*. This formation is widely distributed in the Baron Sog in Sumn and Urtin Obo districts. According to the stratigraphic relation as well as the faunal content, this formation is of Lower Oligocene age. The succession of the strata of the Ulan Gochu beds is shown by the following section:

The formations of the Urtin Obo section are as follows in descending order:

The Oligocene beds

IV. The Baron Sog formation

8. Greenish and grayish coarse sandstones and conglomerates

III. The Ulan Gochu formation

7. Red and pinkish clays
6. White and gray sands
5. Red and pinkish clays
4. White sands

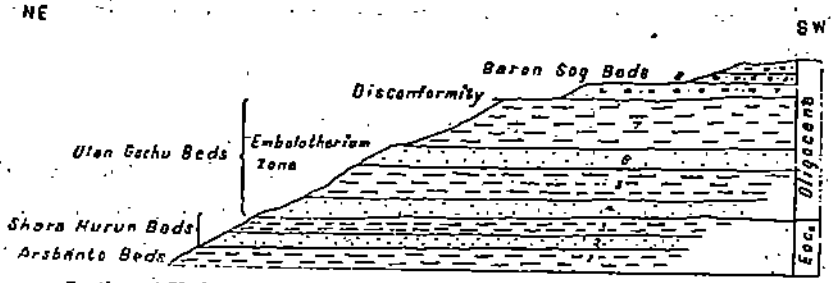

Fig. 3. Section at Urtin Obo, about 75 Miles south west from Margett's Camp (modified after Granger and Spock)

1. Red clay and sands 2. White calcareous sands 3. Red clays 4. White sands 5. Red and pinkish clays 6. White and gray sands 7. Red and pinkish clays 8. Greenish and grayish arkostic sandstones and conglomerates

The Eocene beds

II. The Shara Murun formation

3. Red clays
2. White sands (calcareous)

I. The Arshanto formation

1. Red clay

The Baron Sog formation[1]

1 Berkey, C. P., Granger, W., and Morris, F. K. 1929, Amer. Mus. Novitates, No. 385.

The Baron Sog formation lies disconformably upon the Ulan Gochu beds. It is terminated by a great erosional surface. This formation consists mainly of conglomerates and arkosic sandstones of greenish and yellowish colors; sometimes they are white or gray in color. In the Baron Sog Lama temple district and in the neighbourhood of Urtin Obo, it has a thickness of about 12 meters. But in the Duhum Usu region it is only 2 to 4 meters thick. It represents probably only the middle part of the formation. Even the Ulan Gochu beds and the Shara Murun beds are wanting in the Duhum Usu district. (see Text-figure 3).

This formation is characterized by the diagnostic fossils *Baluchitherium*, the giant hornless rhinoceros, and *Entelodon*, the giant pig. *Embolotherium* is entirely absent from this horizon. According to the faunal content, this formation belongs to the Middle Oligocene or upper part of Lower Oligocene. Judging from the lithologic characters, the Baron Sog beds must be of river channel deposits or river deposits. The flow of the water must have been very fast and violent so that these coarse materials could be transported without difficulty.

The Houldjin Formation.

The Houldjin formation was first discovered by the expedition in Irlian and Irdin Manha districts. It consists of greenish or yellowish sands and gravels. Two miles north east of Duhum Usu the Houldjin beds are also present. *Baluchitherium* bones were also collected by the last expedition.

A table of preliminary Correlation of the Oligocene formations:

	Mongolia		Europe	N. America
L. & M. Olig.	Formations	Life Zone		
	Baron Sog	Baluchitherium	Stampian	M. White River
	Houldjin	Baluchitherium		L. White River
L. O	Ulan Gochu	Embolotherium	Sanoisian	L. White River

Titanotherium are also present from this horizon. Judging from the fauna, the Houldjin formation may be correlated with the Baron Sog beds or a little earlier horizon.

Miocene Period

In Inner Mongolia no trace of Miocene deposits has been found up to the present. According to the recent researches, great erosion predominated in Mongolia in Miocene time and no sediments were deposited. Everywhere

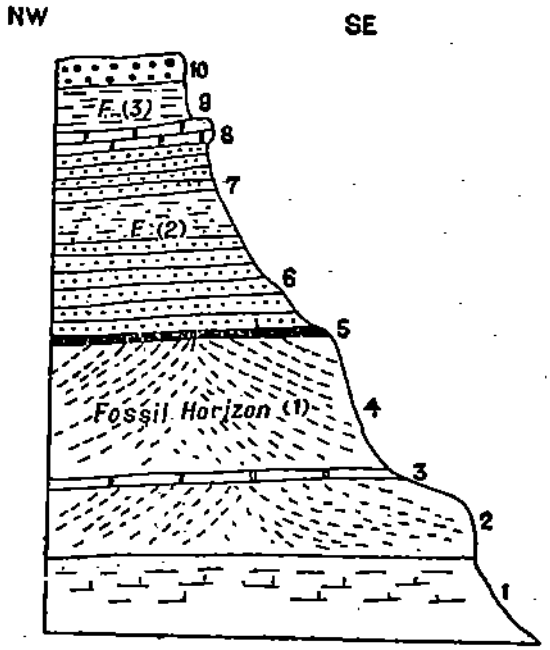

Fig. 4. Section at the Wolf Camp about 9 Miles south west of the well, Gur Tung Khara Usu.

1. Brown sands and marls 2. Cross-bedded white sands 3. Thin layers of limestone 4. Cross-bedded sands 5. Thin layers of peat 6. Fine sands 7. Calcareous sands and marls very fossiliferous 8. Fresh-water limestone 9. Greenish and white sandy clay 10. Residual gravels

above the Oligocene beds follows a great erosion surface. So far the only Miocene formation, was found in the Uskuk Mountain district in Outer Mongolia. That was named the Loh[1] formation by the American geologists. The diagnostic fossils are *Serridentinus mongoliensis* Osborn and *Baluchitherium*

1 Osborn, H. F. 1924. Amer. Mus. Novitates, No. 148.

mongoliense Osborn. On the basis of these fossils, H. F. Osborn has determined the age of the formation as Lower Miocene.

PLIOCENE PERIOD

The Pliocene deposits are very well developed on the east side of the Kalgan-Urga trail and especially on the north east. In 1928 the expedition visited the Gur Tung Khara Usu region and made very extensive explorations and collections. The rocks of this region consist chiefly of sands, clays, and also thin layers of fresh water limestones. The sands are strongly cross-bedded. Judging from the lithologic characters, the sediments are partly of lacustrine and partly of fluviatile origin. They are very rich in vertebrate fossils. Dr. Spock has designated this formation the Tung Gur formation. (P. E. Spock. 1930, Amer. Mus. Novitates, no. 394)

In the expedition last year (1930) we also visited this region; besides this we found several new localities south west of the well Gur Tung Khara Usu. One of the new localities in Ulan-cha-pu (烏蘭查布：漢譯白邊) about 9 miles south west of that well. We named this place Wolf Camp, where we spent the first half of our field season (about seven weeks). One other locality is 4½ miles south of Wolf Camp. These two localities are extremely abundant in fossils and we made a large collection filling about 80 camel boxes. The characters of the sediments are very similar to those of the Elephant Camp, north of Gur Tung Khara Usu. They are mainly sands, clays and some thin layers of fresh water limestones. Marls are also present in the series. But the thickness of the beds and the number of fossil horizons are quite different in different places. I will try to describe it more in detail with the aid of several sections.

1. Section at the Wolf Camp.

The different strata in this section are as follows in descending order:

10.	Residual gravels.....	½	meters
9.	Greenish and white sandy clay.....	2½	,,
8.	Fresh water limestone.....	1½	,,
7.	Calcareous sands and marls very fossiliferous...	5	,,
6.	Fine sands.....	8½	,,

1 Osborn, H. F. 1924, Amer. Mus. Novitates, No. 148

5.	Thin layers of peat.....	½	,,
4.	Cross-bedded sands.....	10	,,
3.	Thin layers of limestone.....	½	,,
2.	Cross-bedded white sands.....	5	,,
1.	Brown sands and marls.....	6	,,

There are three main fossil horizons as indicated in the figure F (1), F (2), and F (3). But the second one is the richest in fossil mammal bones. not only in individuals, but also in orders and families. The bones are scattered quite irregularly, so that in one place they are very numerous but in another place very rare or absent. It seems that the bones were originally deposited in pockets. Besides the three main fossil horizons, bones are also present in the remaining strata but are very rare. From the freshwater limestone, gastropod shells (*Planorbis*) have been collected. In the coarse sands Pelecypod shells (*Unionidæ*) of several species were found. The total thickness of the strata is about 45 meters. The origin of the sediments is partly lacustrine and partly fluviatile.

A preliminary faunal list collected at the Wolf Camp determined in the field is as follows:

Perisodactyla
- *Rhinoceros*
- *Chalicotherium*
- *Hipparion*

Artiodactyla
- *Antelope*
- *Cervus*

Proboscidea
- *Mastodon* (rounded lower tusked)
- *Platybelodon* (flat tusked)

Rodentia
- *Mus*

Reptilia
- Land *tortoise*

Pelecypoda (Unionidæ)

Gastropoda (Planorbis)

II. Section at the Bolhow district about 30 miles north east from Wolf Camp.

The succession of the strata is as follow:

6. Residual gravels
5. Yellow sands
4. Greenish yellow sandy shale
3. Rusty coarse sandstones
2. Fine sands
1. Red clays.

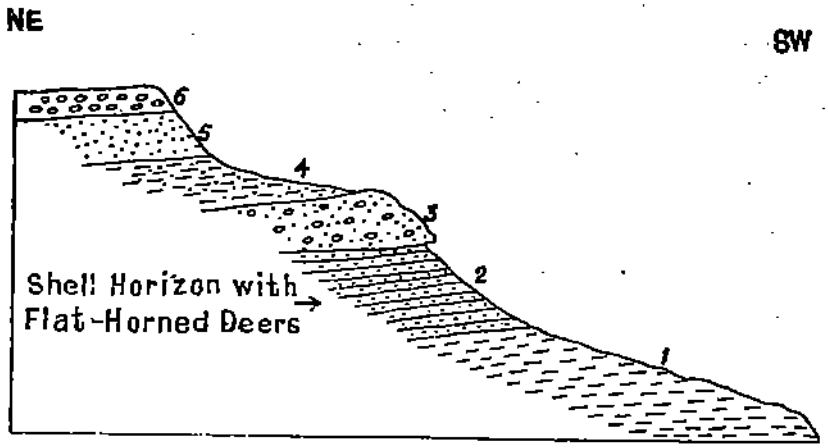

Fig. 5. The Geological section at the Bolhow district about 30 Miles north east from Wolf Camp.

1. Red clays 2. Fine sands 3. Rusty coarse sandstones 4. Greenish yellow sandy shale 5. Yellow sands 6. Residual gravels

At this locality two things are worthy of notice. First the sequence of strata is quite different from that at Wolf Camp. Secondly the mammal bones collected are also of different types. From lower part of the stratum No. 2 as shown in the figure a great number of horns of deer were collected. Most of these are flat. The shape as well the number of branches of the antlers are quite different. They represent at least four species. Teeth of deer were seldom found. Mastodont fragments and teeth of chalicotheres were also collected from this horizon. In stratum No. 5 skulls and jaws of rhinoceros were collected.

Owing to the differences both from the sequence of strata and of faunas, the stratigraphic correlation in the below region becomes very difficult. It is hard to say, whether they represent a higher or lower horizon than that of Wolf Camp or are equivalent. According to the field observations they are probably a little lower than the formations of Wolf Camp.

III. Section at the Platybelodon quarry 5 miles south from Wolf Camp.

At this locality only the upper-most part of the strata is exposed. The thickness as well as the extension of the exposure is not very large. But the fossil content is exceedingly rich. It is a strange fact that most of the mammal bones belong almost to the same Genus *Platybelodon*, the flat, scoop-like, lower tusked Proboscideans. It is also very strange, that more than twenty-five lower jaws of this animals were collected but only a few skulls and upper

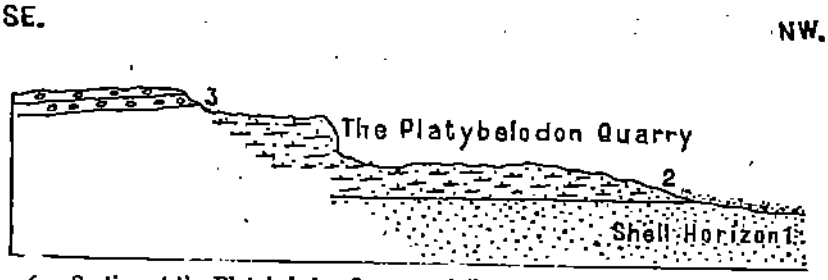

Fig. 6. Section at the Platybelodon Quarry, 5 Miles south from Wolf Camp.
1. White fine sands with shells 2. White and gray calcareous sands and marls 3. Residual gravels

tusks were found. Except the bones of *Platybelodon* there are only a few fragments of *Rhinoceros* and a single tooth of *Carnivora*. All these fossil bones were buried in quite a small area perhaps not more than 40 square yards. The death of those animals, buried in the sediments must have been caused by an abrupt catastroph. They might have drowned there while searching for water after a long time of draught.

Now I shall return to the age of the Pliocene deposits. The exact age of these sediments is very difficult to determine at present before the collections have been thoroughly studied. According to the fauna viewed as a whole, it must be lower Pliocene, the equivalent of Pontian of Europe. Different horizons may be represented in different localities, as is frequently the case in the basin sediments of the Gobi.

Conclusions

From the foregoing, we see that the Tertiary formations in Mongolia are very completely represented and well developed. They contain a very rich and well preserved fauna. If we recall to mind the Tertiary formations of Europe and North America and make a comparison and correlation with those of Mongolia we can see immediately that the older Tertiary formations of Mongolia are much better represented than those of Europe. The best known Older Tertiary formations in Europe are the conglomerate in Cernay (Reim), Gipse de Montmartre, the fissure deposits of phosphorite of Quercy in south France, and the Bohnerze in Swabia (Fronstetten), south Germany, and in Egerkingen in Switzerland. Most of these are fissure deposits and they are of very limited distribution. In North America, the Older Tertiary formations are very well represented and of wide distribution. Through long years of researches by American palæontologists, the mammal fauna of these beds have become well known to the scientific world. The Younger Tertiary formations of North America are, however, still imperfectly known and less extensive than those of Europe and Asia. The best known localities of Younger Tertiary formations in Europe are Pikermi in Greece, Mont Léberon and Montpellier in France, the Dinotherium sand of the Mainz Basun in Germany, and the Belvedere-schotter of the Vienn Basin in Austria. The sediments of the Siwalik Hills and of Maragha are the most famous ones in Asia except those in Mongolia. For the convenience of comparison, a table of correlation is here given. It is of course only a preliminary one and aims only at broad parallelization and of course subject to correction in the future.

蒙古二廟古爾東烏蘇及西蘇食喇嘛廟一帶地質畧圖

SKETCH MAP OF THE IREN DABASU, GUR TUNG KHARA USU & BARON SOG IN SUNM DISTRICTS IN INNER MONGLIA.

張席褆製 By H. C. Chang 1930