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Litho-, Bio-, and Magnetostratigraphy and Paleoenvironment of Tunggur Formation (Middle Miocene) in Central Inner Mongolia, China

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ABSTRACT

The Tunggur Formation is presently exposed along the edge of the Tunggur Tableland. Being mostly flat-lying and with a maximum thickness of less than 80 m (most sections are less than 40 m thick), exposures along the northern, western, and southern edges of the platform all produce vertebrate fossils. The American Museum Wolf Camp Quarry and *Platybelodon* Quarry produced most of the early collections. To the east, the Tableland gradually blends into the landscape, and its distribution becomes less well delineated. At the extreme eastern end, the Tunggur Formation is probably overlain by the late Miocene Baogeda Ula Formation. The Tunggur Formation has its stratotype along a small exposure at Mandelin Chabu in the northwest edge of the Tableland.

The Tunggur Formation in the Tableland is divided into two informal sedimentary units, the upper and lower beds. The stratotype section, Wolf Camp, and *Platybelodon* Quarry, along with most localities in the northern escarpment, belong to the upper beds, which are characterized by cross-bedded sandstones, variegated mudstones, and occasional marls. The entire southern Tairum Nor badland and lower part of the Aletexire section belong to the lower beds, which are characterized by more uniform red mudstones interrupted by a channel sandstone. The upper beds produce the Tunggur Fauna, which includes most of what is traditionally known as the *Platybelodon* Fauna. The lower beds contain a more recently named Tairum Nor

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Fauna, which has the latest occurrence of *Tachyoryctoides* and three musteloid carnivorans: *Leptarctus neimenguensis*, a new species of *Sthenictis*, and a new form possibly related to *Aelurocyon*, with all three being well represented in the North American Miocene.

Paleomagnetic study of two key sections at Moergen small mammal locality and at Tairum Nor locality suggests a correlation in the magnetozones C5Ar.3r through part of C5r.3r, with an age range of 11.8–13 Ma. Systematic prospecting in known and previously unexplored areas has resulted in an expansion of the faunal representations in the region. By integrating the faunal data with magnetostratigraphy, we provide the first chronological tie point in the Chinese middle Miocene mammalian stratigraphy. Paleoenvironmental studies of the Tunggur Formation indicate a mosaic of grassland and mixed conifer–broadleaf woodland. Shallow channels were abundant, and floodplains had undergone different degrees of soil formation. Large mammal communities contain many low-crowned browsers and a few high-crowned grazers, but small mammals are dominated by grassland-adapted forms.

INTRODUCTION

In 1928, the Central Asiatic Expedition by the American Museum of Natural History found the first ‘‘Pliocene’’ locality near a freshwater well known as Gur Tung Khara Usu in central Inner Mongolia, China (Andrews, 1932; Spock, 1929). Thus began a series of sensational discoveries that produced a fossil mammal assemblage best known for its shovel-tusked elephant *Platybelodon grangeri*. For a long time Tunggur was the only Chinese middle Miocene locality widely known in the world. This pre-*Hipparion* (three-toed horse) fauna, one of the richest in the Chinese middle Miocene, became the basis of the Tunggurian land mammal age in East Asia. Despite this promising start, however, geological exploration of the region was discontinued because of wars and political instabilities. With the exceptions of a brief exploration by a Sino-Soviet Paleontological Expedition in 1959 and more recent fieldwork by the Institute of Vertebrate Paleontology and Paleoanthropology in 1986–1987 (see History of Study below), no systematic field study was attempted. As a result, much basic information is lacking, such as the status of the type section and the locations of historically important localities. Without such information, faunas from historical collections were often scrambled into a single heterogeneous assemblage.

The present field studies, carried out between 1993 and 2000, attempt to address five basic issues: (1) to relocate classic localities; (2) to establish lithological and biostratigraphic criteria for correlation within Tunggur strata; (3) to conduct paleomagnetic studies of key sections; (4) to update the faunal lists produced from each localities; and (5) to summarize evidence for paleoenvironments of the regime.

INSTITUTIONAL ABBREVIATIONS: **AMNH,** American Museum of Natural History, New York; **CAE,** Central Asiatic Expedition; **F:AM,** Frick Collection of American Museum of Natural History, New York; **IVPP,** Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Beijing; and **SSPE,** Sino-Soviet Paleontological Expedition.

METHODS

Geographic names of the Tunggur area have been complicated by a combination of cross-translations among English (sometimes French), Mongolian, Chinese, and occasionally Manchurian. Mongolian location names in early publications were sometimes translated to Chinese, which were subject to interpretations by individuals with different backgrounds in Chinese dialects, and finally to English, which can be based on either Wade-Gile or Pinyin systems. To compound these problems, Mongolian location names may change within a short time because nomadic tribes have no permanent settlement. With the exception of well-established names, such as Tunggur and Tairum Nor, we use names published in Chinese 1:100,000 topographic maps (published in 1971). These Chinese translations of Mongolian names are further translated to English in the standard Pinyin system of the People’s Republic of China.

CAE archive photographs of the Tunggur

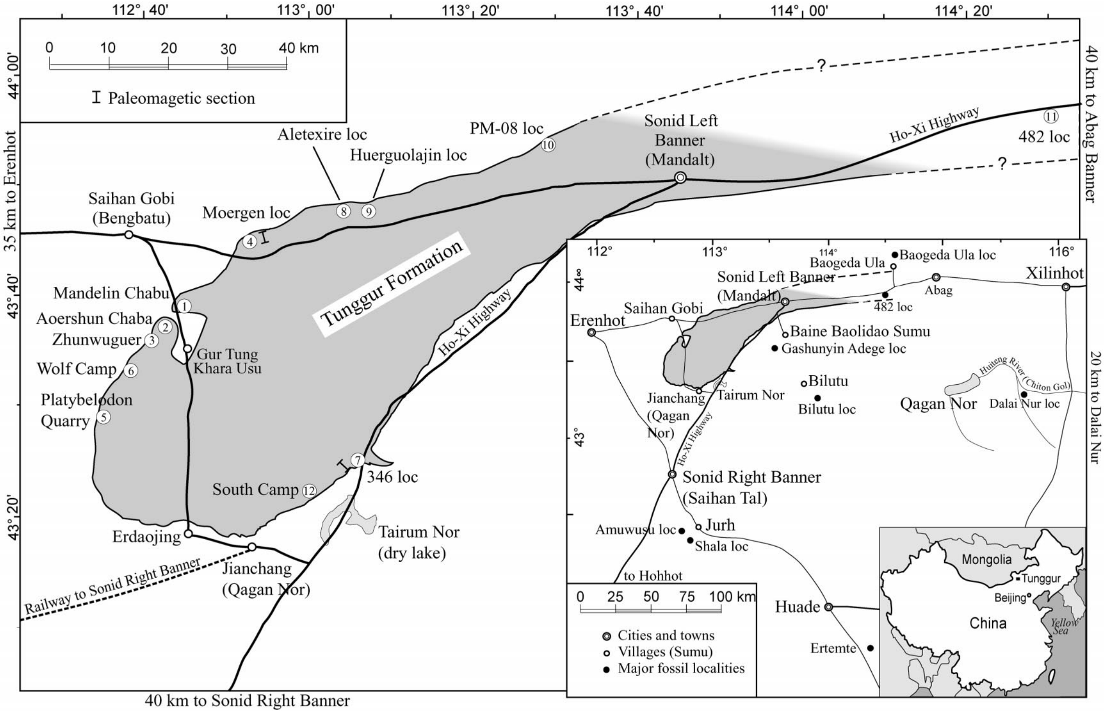


Fig. 1. Geologic map of the Tunggur Formation. The boundaries of the Tunggur Formation (shaded gray) follow the escarpment of the Tunggur Tableland shown on the Chinese topographic map (Cartographic Bureau of People's Liberation Army, 1972). Where there is no clear topographic relief the boundary is more difficult to draw (shown in dashed lines). Maps in inset indicate important regional landmarks and localities.

localities are stored in the general library of the American Museum of Natural History. Latitudinal and longitudinal coordinates were measured by a Trimble Navigation Scout Master GPS (global positioning system) set in the WGS-72 mapping datum. All GPS measurements were taken before May 1, 2000, when the ''selective availability'' (a form of data degradation) was switched off by the Department of Defense of the United States, and thus they have a degraded accuracy of ±30 m.

HISTORY OF COLLECTIONS

In June 1928, Roy Chapman Andrews of the American Museum Central Asiatic Expeditions made an excursion southeast of the Eren Dabasu (the present day city of Erenhot), a vast area only briefly explored in the southern parts by Swedish geologist J. G. Andersson and French vertebrate paleontologist P. Teilhard de Chardin (Andersson, 1923; Teilhard de Chardin, 1926a, b). In a fluvial sand exposure 50 miles southeast of Erenhot, Andrews' team found a partial ''mastodon'' skeleton near a well named Gur Tung Khara Usu (Andrews, 1932) (Fig. 1). Fieldwork for more than 10 days resulted in a small collection of two species of proboscideans, a carnivore, a chalicothere, a rhino, a cervid, an antelope, some turtle shells, and freshwater bivalves. The fossil vertebrates were estimated to be ''Pliocene'' in age, representing a previously unknown fauna, and the bone bed was promptly reported by L. E. Spock (1929) as Tung Gur Formation, a name reversed from the local well Gur Tung Khara Usu.

After a one-year hiatus, the CAE team carried out a more extensive expedition in the Tunggur area in 1930. Collections were concentrated in two new localities, *Platybelodon*

Quarry and Wolf Camp (Fig. 1). The *Platybelodon* Quarry yielded a series of exquisitely preserved *Platybelodon* skeletons, ranging from infants to full adults, and the Wolf Camp produced a rich variety of medium-sized mammals. Together with a few other lesser known localities, the Tunggur Formation produced 28 species of mammals, most of them new to science. These fossils, housed in the AMNH, were subsequently described by various specialists: two proboscideans (Osborn, 1929; Osborn and Granger, 1931, 1932), one anchitheriine horse (Colbert, 1939b), one chalicothere (Colbert, 1934a), eight carnivorans (Colbert, 1939a; Hunt and Solounias, 1991), one suid (Colbert, 1934b), two bovids (Pilgrim, 1934), four cervids (Colbert, 1936b, 1940), one giraffe (Colbert, 1936a), four rodents (Stirton, 1934; B.-y. Wang, 1988; Wood, 1936), two lagomorphs (Dawson, 1961), and three rhinocerotids (Cerdeño, 1996) (see table 1 for a list of taxa and their occurrences).

Wars and political difficulties prevented further exploration of these rich deposits until 30 years later when a brief visit to the Tunggur area was organized by a joint Sino-Soviet Paleontological Expedition in 1959 (Chow and Rozhdestvensky, 1960). Materials obtained from this expedition, however, were mostly lost or destroyed as relationships between the two countries deteriorated, and only two new taxa, a beaver and a carnivore, were published as a result of this expedition (Li, 1963; Zhai, 1964). After another long hiatus, a renewed effort by the IVPP in 1986–1987 led to substantial progress both in geology and paleontology (Z.-x. Qiu et al., 1988). In particular, intensive screen-washing at the Moergen locality yielded more than 20 species of small mammals, nearly doubling the previously known number of taxa, and correcting the traditional bias against small mammals in the early collections. The most important result of this latter expedition is a monograph on Tunggur small mammals (Z.-d. Qiu, 1996). In a follow-up study, we attempted to correlate small mammal faunas in and around the Tunggur area (Z.-d. Qiu and Wang, 1999), which includes faunas from early Miocene to Pliocene. Within the Tunggur Formation, we differentiated a new fauna near Tairum Nor, which is older than the classic Tunggur fauna.

Independently, various regional geological survey teams have attempted to synthesize the local geology into a mappable regional framework (e.g., Bureau of Geology and Mineral Resources of Nei Mongol Autonomous Region, 1991), which were often too coarse an outline to be of assistance in field studies. More recently, Dong Mingxing (1993), a graduate student of China University of Geoscience, briefly explored problems related to the regional correlation and depositional environment of the Tunggur Formation. However, with the exception of two brief reports on contact relationships and fossil tracks (Dong, 1999; Dong and Ai, 2001), he did not publish his thesis.

GEOLOGICAL SETTING

Cenozoic deposits east of Erenhot generally lie in the upper part of the fill of a series of northeast–southwest oriented rift subbasins. Collectively, these fault-controlled subbasins form the Eren Basin, initially filled in the Jurassic through Cretaceous by fluviolacustrine deposits and often forming half grabens or asymmetric grabens, up to 3–5 km thick (Lin et al., 2001). The Mesozoic deposits are mostly in the subsurface, but they may crop out in basin margins, as near the Qagan Nor Chemical Factory (Jianchang in fig. 1).

In central Inner Mongolia between the cities of Erenhot and Xilinhot is a large span of rolling plains with few notable landmarks (inset map in fig. 1). Besides occasional patches of granites, usually weathered to ground levels, the most conspicuous features are a series of low tablelands, commonly 40–80 m above ground level and forming elevated benches that extend tens of kilometers in a single stretch. Outcrops along their edges often produce fossils. The Tunggur Tableland is outlined in a northeast–southwest-oriented, tongue-shaped platform, although its northeastern extent becomes gradually less well defined (fig. 1). To the east, another large tableland near Baogeda Ula is capped by a lava, forming a well-defined platform. Late Miocene in age, this latter tableland is similar to another series of lava-capped platforms along the Huiteng River (Chiton Gol) farther southeast of Tunggur, as first explored by Teilhard de Chardin (1926b).

Neogene deposits at Tunggur and surrounding areas are often confined to small basins of just a few square kilometers that are less than a few meters in thickness (e.g., Gashunyin Adege, Shala, Amuwusu; see fig. 1). The Tunggur Formation and the overlying Baogeda Ula Formation, on the other hand, represent much larger depositional basins of several hundred square kilometers in size and up to 100 m in thickness. Over the entire Tableland the Tunggur Formation is flat-lying, and structural disturbance of these rocks is minimal. Teilhard de Chardin (1926b) described volcanic cones along the Huiteng River area south of Xilinhot. Basalt lava sheets from these eruptions, several meters thick in some places, top the presumed Baogeda Ula Formation and form a resistant bench. Their fresh appearance suggests a young age (Whitford-Stark, 1987), and recent K-Ar radiometric dates indicate at least three episodes of eruptions (3.27, 2.08, and 0.47 Ma) during the late Pliocene through Pleistocene (Liu, 1999). These lava sheets and the underlying Baogeda Ula Formation form the most conspicuous tablelands to the south and west of Xilinhot. The Tunggur Tableland, however, is not capped by the lava, which lies too far to the south and east. Instead, the topography of the Tunggur Tableland is mostly shaped by resistant marls or sandstones. Where there is no marl or sandstone, the Tableland tends to gradually blend into the lowland, and exposures are covered by vegetation.

Contact relationships of the Tunggur Formation with rocks above and below were not an issue during the CAE and Sino-Soviet expeditions. Z.-x. Qiu et al. (1988: 403) first cited a locality ‘‘25 km northeast to Saihan Gobi’’ to the north of the Tunggur Tableland as producing *Lophiomeryx*, ‘‘indicating the Oligocene age of the fossil-bearing beds’’, although they acknowledged that no direct contact can be observed between Tunggur Formation and its underlying deposits. Dong and Ai (2001) recently reported some fragmentary materials of a brontothere *Protitan* and a chalicothere *Eomoropus* in a locality (43°31′21″N, 113°13′07″E) not far from the northern rim of the Tunggur Tableland at an elevation of 986 m. They placed these two forms in the middle Eocene Irdin Manha Formation and recorded a disconformable contact between the Tunggur Formation and the underlying Irdin Manha Formation. To the south of the tableland, Meng et al. (1996) recently reported a new fauna of early Miocene age from Gashunyin Adege (see also Z.-d. Qiu and Wang, 1999). The Gashunyin deposits, however, are confined within a small basin in an area of granite basement rocks, and they are unlikely to be superposed by the Tunggur Formation.

As for the overlying sediments, the Editorial Committee of Stratigraphic Table of Inner Mongolia Autonomous Region (1978) first established the Baogeda Ula Formation based on escarpments near the village of Baogeda Ula, approximately 20 km northeast of the easternmost Tunggur locality, Roadmark 482 Loc. However, the base of the Baogeda Ula Formation, which contains a *Hipparion* fauna, cannot be observed at the type section. The 482 locality is the only section where a conglomerate is seen to overlie disconformably on the Tunggur Formation (see fig. 8). Although the thin conglomerate (1 m) cannot be directly correlated to the type section of the Baogeda Ula Formation, its geographic proximity and fossil content suggest this contact relationship relative to Tunggur Formation.

DESCRIPTION OF TUNGGUR LOCALITIES

Spock’s (1929) original description of the Tunggur Formation is sketchy, and all localities were in reference to a single well ‘‘Gur Tung Khara Usu’’ (see further comments below). Spock reversed the first two words to coin the stratigraphic unit ‘‘Tung Gur Formation’’. Osborn and Granger (1932: fig. 1) subsequently used ‘‘Tung Gur Tableland’’ to refer to a low plateau, whose escarpments along the northern, western, and southern edges form the exposures of the Tunggur Formation. We continue this usage and the name Tunggur thus refers to ‘‘the whole area where the Tung-gur Formation is actually or potentially exposed’’ (Z.-x. Qiu et al., 1988: 400). The original spelling of ‘‘Tung Gur

Formation'' in Spock (1929) was subsequently modified to ''Tung-gur Formation'' by Z.-x. Qiu et al. (1988) and further simplified to ''Tunggur Formation'' in Z.-d. Qiu (1996). We follow this latest form throughout this text.

Precise location of the stratotype and other CAE localities in the Tunggur area was hampered by the lack of precise topographic maps, scarcity of geographic reference points in an essentially featureless terrain, and often inadequate photographic or descriptive documentation of the exposures and rock sequences. Subsequent field studies, widely separated in time and by different groups of people, had only the sketch map published by Osborn and Granger (1932: fig. 1) for reference. The 1959 Sino-Soviet Paleontological Expeditions concentrated on a few quarries, and their collections made minimal reference to the historical localities (Chow and Rozhdestvensky, 1960). The IVPP 1986–1987 field teams attempted to relocate the CAE localities, this time with the benefit of accurate Chinese 1:100,000 topographic maps (Cartographic Bureau of People's Liberation Army, 1972). The IVPP team tried to reconcile their findings on the basis of Osborn and Granger's sketch map and a few distance estimates made by Andrews (1932), which may account for many of the errors in their estimates (see description of localities below). Z.-x. Qiu et al.'s map (1988: fig.1) is essentially that of Osborn and Granger's (1932: fig. 1), whereas Z.-d. Qiu (1996: fig. 1) adopted the Chinese topographic map but still used the relative positioning of the various localities in Z.-x. Qiu et al. (1988). Our own map is based on the same topographic map, with the GPS positions being plotted in Figure 1.

AMNH ''Gur Tung Khara Usu''

A commonly referenced, and confused, landmark in the Tunggur Tableland is the so-called ''Gur Tung Khara Usu''. Since this was one of few Mongolian geographic names (most others were coined by the CAE team) and serves as the sole geographic reference point for all other fossil localities, it is a matter of importance to relocate this landmark.

The name ''Gur Tung Khara Usu'' referred to a freshwater well frequently used by the local herdsmen. The well ''lies in a deep basin surrounded by poorly exposed bluffs'' (Andrews, 1932: 386). This lowland, which is well delineated on the topographic map, covers several square kilometers and contains within it at least five wells, as marked on the topomap. Two major wells, however, are more likely candidates for Gur Tung Khara Usu because they are converging points of multiple trails, which were also indicated by Andrews (1932); the other three wells have dried up and there is no more than one trail leading to them. On the Chinese topographic map, the two active wells are named the Donghuren Huduge and the Gulin Huduge (''Huduge'' means well in Mongolian). The two wells are separated by approximately 4 km, and presumably one of them was once called Gur Tung. Gulin Huduge (43°35′10″N, 112°45′00″E, elevation 1015 m) seems a more likely choice because of its closer match to the distance estimates by the CAE (see map in fig. 1).

AMNH Mandelin Chabu
(Figure 2)

GPS Location: 43°38′20.9″N, 112°45′37.6″E.

Elevation at Top of Section: 1061 m.

Synonyms: ''Elephant Camp'' in Andrews (1932: 406); ''Mastodon Camp'' in Andrews (1932: 429–430); ''N. Camp 1928'' in Osborn and Granger (1932: fig. 1); ''Gur Tung Khara Usu'' in many labels of the AMNH collection; and IVPP loc. 86023, ''Mandelin Chaba'' (Z.-d. Qiu, 1996; Z.-x. Qiu et al., 1988).

Remarks: This is the stratotype section of the Tunggur Formation as originally defined by Spock (1929), and it is 7 km (4.3 mi) north of the Gulin Huduge. Recognition of the type section is helped by its unique position on the northeastern rim of a small embayment along the northern edge of the Tunggur Tableland escarpment (see Osborn and Granger, 1932: fig. 1). An exact match of Spock's photograph of the type locality (1929: fig. 2) (AMNH photo archive no. 411010) can be made at the above GPS location looking eastward. A minor dry stream carves across the foreground of Spock's pho-

Fig. 2. Type locality of Tunggur Formation at Mandelin Chabu. Photograph taken during 1928 expedition, looking east. Negative no. 411020, courtesy Department of Library Services, American Museum of Natural History.

tograph, as can still be seen today. Large bone fragments could be found near the presumed spots where rhino and proboscidean skeletons were collected a few hundred meters west of the North Camp.

The local rock sequence consists of sandstones and mudstones capped by a thin marl (immediately below the North Camp) or a hard cross-bedded sand (slightly southwest of the North Camp). As depicted in Spock's figure 4, exposures to the west still preserve more than 2 m of coarse cross-bedded sands above the marl, whereas the eastern section has lost the sands above the marl. The measured section of IVPP loc. 86023 (Z.-x. Qiu et al., 1988: 403) is probably a few hundred meters farther east of the type section.

SSPE Aoershun Chaba

GPS LOCATION: 43°36′53.4″N, 112°43′50.8″E.

ELEVATION AT TOP OF SECTION: 1067 m.

SYNONYMS: SSPE ''Tung Gur locality'' (Chow and Rozhdestvensky, 1960: 5); ''18 km south of Benbatu (= Saihan Gobi)'' (Li, 1963; Zhai, 1964); IVPP loc. 86018, ''Aoershen Chabe'' (Z.-x. Qiu et al., 1988: fig. 1); ''Aoershun Chabu'' (Z.-d. Qiu, 1996: fig. 1).

REMARKS: Approximately 4 km southwest of Mandelin Chabu, this locality is the closest to the stratotype. It was quarried for three weeks by the Sino-Soviet Expedition in 1959 (Chow and Rozhdestvensky, 1960), and in partially refilled trenches dug out by bulldozers, rusty-yellow sandstones are still visible. Aoershun means ''Russia'' in Mongolian and refers to the low hills (top elevation 1063 m) formed by reddish mudstones capped by rusty-yellow sands. Li (1963) and Zhai (1964) described ''*Monosaulax*'' *tungurensis* and *Percrocuta tungurensis* from ''18 km south of Benbatu'' collected during the Sino-Soviet Expedition. Both Aoershun Chaba and Zhunwuguer (see below) more or less fit in this description, but the former is more likely the locality because the latter was probably not prospected during that trip.

The lower beds are a sequence of variegated mudstones, followed by a buff sand and capped by a layer of rusty-yellow sands, which was bulldozed by the Sino-Soviet team. Chow and Rozhdestvensky (1960: 5) mentioned the recovery of two partial skeletons of mastodonts, several skulls and jaws of mastodonts and rhinocerotids, as well as cervids and carnivores. However, besides the abovementioned ''*Monosaulax*'' and *Percrocuta*, most materials were never accounted for and were presumably destroyed or lost during the Cultural Revolution.

IVPP Zhunwuguer Locality

GPS LOCATION: 43°36′07.0″N, 112°41′ 01.9″E.

ELEVATION AT TOP OF SECTION: 1053 m.

SYNONYMS: IVPP loc. 86019, ''South Zhunwuguer'' and ''Wolf Camp'' (Z.-x. Qiu et al., 1988); ''Wolf Camp'' of Z.-d. Qiu (1996: fig. 1).

REMARKS: Less than 4 km southwest of the Aoershun Chabu is an exposure about 1 km long. An isolated small hill, a few hundred meters from the main edge of the Tableland, is called Zhunwuguer with an elevation of 1037.1 m on the topographic map. Andrews (1932: 431) described his discovery of a ''round-tusked mastodon'' mandible from ''an isolated rounded hill . . . well out in the basin'' (the specimen became the type of *Serridentinus gobiensis* Osborn and Granger, 1932). Andrews' isolated hill is probably Zhunwuguer, based on its distance (6.2 km) to the AMNH Wolf Camp (Osborn and Granger, 1932: fig. 1). The holotype of *Lagomeryx triacuminatus* was from ''about five miles west of Gur Tung Khara Usu'' (Colbert, 1936b: 12). Lacking a more precise description, this locality is also considered Zhunwuguer or nearby.

Large exposures south and southeast of the Zhunwuguer hill were established as IVPP loc. 86019 and mistakenly identified by the 1986 field team as the CAE ''Wolf Camp'' (Z.-d. Qiu, 1996; Z.-x. Qiu et al., 1988). We now conclude that the original Wolf Camp is located 6 km farther south (see below).

AMNH Wolf Camp
(Figure 3)

GPS LOCATION: 43°32′57.3″N, 112°39′ 427.5″E.

ELEVATION AT TOP OF SECTION: 1065 m.

SYNONYM: ''General Quarry No. 2'' in Osborn and Granger (1932).

REMARKS: Andrews (1932: 431) described the discovery of this important locality, which produced many well-preserved fossils. He named the locality Wolf Camp because the campsite ''was infested by wolves''. The Wolf Camp was pitched ''on a jutting promontory'' protruding into the west, and had otherwise no other geographic distinctions. Fortunately, two CAE archive photographs are available, and one of them, AMNH archive no. 116819, shows an erosional cliff of a local marl layer, which is uniquely shaped as a hard cap (arrows in fig. 3A, B). Standing on a spot at 43°32′50.3″N, 112°39′25.1″E and looking to the north, no. 116819 can be duplicated with all of the details of the land forms (fig. 3B). Two hundred meters to the northeast is the promontory where the Wolf Camp was located, where a second archive photo (AMNH archive no. 116816) can be matched. Also in support of its identity as the Wolf Camp is the fact that this is one the largest exposures on the western rim of the Tunggur Tableland, with well-exposed cross-bedded sands and bivalves, a likely place to yield abundant large mammals. The Wolf Camp is 5.9 mi (9.5 km) southwest of the Gulin Huduge (as compared with 5–6 miles in the historical record). Sand dunes covered many exposures in the Wolf Camp in the 2000 season.

Almost all of the vertebrate fossils were collected by the CAE in 1930 (both SSPE and IVPP 1986 field seasons failed to correctly locate the AMNH Wolf Camp). At least two fossiliferous horizons are present in our investigations, one below the lower channel sandstone or immediately above it and another at a much higher level just below the top marl. Unfortunately, no field record was kept about which level the historical collections came from.

IVPP Dabuhaer Locality

GPS LOCATION: 43°32′34.0″N, 112°37′ 52.9″E.

SYNONYM: IVPP loc. 86022 (Z.-x. Qiu et al., 1988).

REMARKS: Two kilometers southwest of

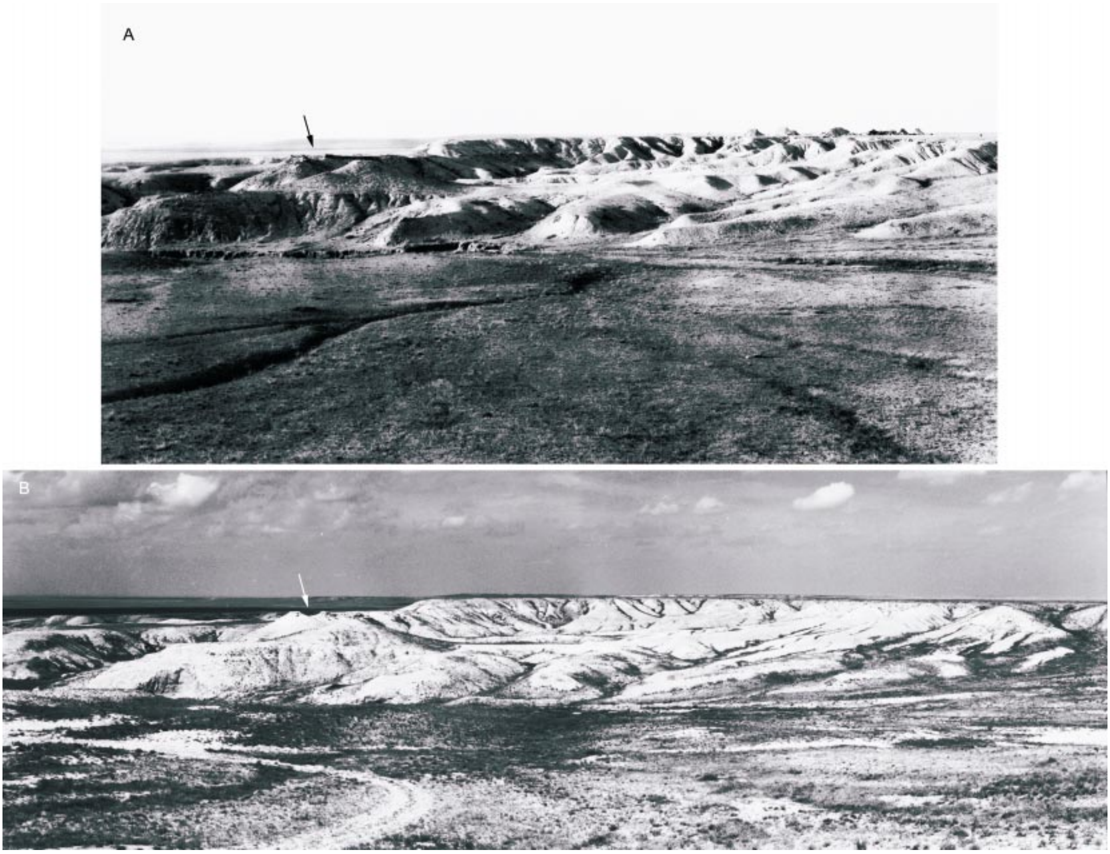


Fig. 3. AMNH Wolf Camp locality. **A,** Field photo taken during 1930 expedition, looking north, negative no. 116819, courtesy Department of Library Services, American Museum of Natural History; tents near right side are original Wolf Camp site; **B,** matching photograph taken in 1996. Arrows indicate erosional gap of the top marl layer, which is correlated to a similar bed at the *Platybelodon* Quarry.

the Wolf Camp is a small exposure near Dabuhaer on the topographic map, with an elevation of 1083.4 m. This locality was thought to be close to the AMNH *Platybelodon* Quarry (Z.-x. Qiu et al., 1988: fig. 1), but the latter is actually 7 km farther south (see below).

AMNH *Platybelodon* Quarry
(Figure 4)

GPS LOCATION: 43°28′54.0″N, 112°36′07.6″E.

ELEVATION AT TOP OF SECTION: 1060 m.

SYNONYMS: ‘‘Mastodon quarry’’ in Andrews (1932: 437); ‘‘Big mastodon quarry’’ in Andrew (1932); ‘‘*Platybelodon* Quarry No. 1’’ in Osborn and Granger (1932).

REMARKS: Situated in the eastern end of an east–west-oriented wash draining toward the west, the *Platybelodon* Quarry is surrounded by small exposures in the north, east, and south. Although the *Platybelodon* Quarry is small (less than 30 × 30 m) and its surrounding exposures are inconspicuous, extensive excavations at this quarry permitted opportunities for better photographic documentation of this locality than other sites. These pictures (AMNH archive nos. 116833–36) show the quarry position relative to the background in all four directions. The light green mudstones prominently displayed to the south of the quarry in AMNH no. 116836 are especially distinctive, and combined with other photos positively identified this quarry. Numerous proboscidean bone fragments are presently scattered in and around the quarry.

Fig. 4. AMNH *Platybelodon* Quarry. **A,** Field photo taken during 1930 expedition, looking north, negative no. 116836, courtesy Department of Library Services, American Museum of Natural History; **B,** matching photograph taken in 1996.

Andrews (1932: 434) described the *Platybelodon* Quarry in ''an amphitheater in the badlands, capped on the western side with snow-white marl.'' This latter marl, very limited in extent, can be observed 200 m southwest of the quarry where it forms a hard cap of the exposure. At the horizon of the actual *Platybelodon* Quarry, there are large blocks (up to 50 cm across) of well-cemented calcareous nodules. The *Platybelodon* Quarry is 17.4 km (10.8 mi, compared with 10 mi in the CAE estimate) southwest of the Gulin Huduge, and 8.8 km (5.5 mi, compared with 6 mi in the original estimate) south of the Wolf Camp.

Near the top rim of the Tunggur Tableland, the *Platybelodon* Quarry is rather high in stratigraphic position, probably close to the top marl layer at the Wolf Camp section.

IVPP Moergen Locality
(Figure 5)

GPS LOCATION: 43°44′41.3″N, 112°54′ 02.6″E.

ELEVATION AT TOP OF SECTION: 1053 m.

SYNONYMS: Probably CAE locality of ''15 miles northeast of Gur Tung Khara Usu''; probably SSPE locality of ''Tabchintala'' (Chow and Rozhdestvensky, 1960: 5); IVPP loc. 86020 (Z.-d. Qiu, 1996; Z.-x. Qiu et al., 1988).

REMARKS: This is one of most intensively worked localities in the IVPP 1986 field season. As the principal small mammal locality, much of the screen washing was done here. With the exception of IVPP loc. 86026, the Moergen locality also has the thickest and most complete exposure along the northern

Fig. 5. The upper beds of Moergen locality, showing red beds in the lower part and marls at the top (light colored), looking toward north.

escarpments of the Tunggur Tableland, which was why we selected this locality as our first paleomagnetic section.

The CAE likely had visited this locality, whose east–west-oriented exposure is conspicuous (more than 2 km long). It is 22–23 km (13.7–14.3 mi) northeast of the Gulin Huduge, falling between the distance estimates of two CAE localities, that is, ‘‘10 miles northeast of Gur Tung’’ and ‘‘15 miles northeast of Gur Tung’’. In the absence of other evidence, however, it is difficult to determine which one, if any, of the two localities corresponds to Moergen.

Along the northern escarpment of the Tunggur Tableland, there are various parts of the grassland bearing the identical name Tamuqintala in the Chinese topographic map. The name is likely the same as ‘‘Tabchintala’’, a ‘‘new locality’’ mentioned by Chow and Rozhdestvensky (1960: 5), which was supposed to be 20 km from ‘‘Tung Gur’’. Since the ‘‘Tung Gur locality’’ means Aoershun Chaba (see above) in Chow and Rozhdestvensky (1960), we equate ‘‘Tabchintala’’ with the Moergen locality, which is 20 km east of Aoershun Chaba.

Much of the Moergen section exemplifies the characteristic sequence of the upper beds of the Tunggur Formation, with massive channel sands in the lower part followed by a middle red mudstone layer and topped by a greenish marl. The basal 5 m of dark brown mudstone probably corresponds to the lower bed of the Tunggur Formation (see correlation below).

IVPP Aletexire Locality
(Figure 6)

GPS Location: 43°47′21.6″N, 113°05′ 25.0″E.

Elevation at Top of Section: 1038 m.

Synonyms: Probably CAE locality ‘‘20 miles northeast of Gur Tung Khara Usu’’ (Colbert, 1939a: 59); IVPP loc. 86026, ‘‘2 km northwest to the tripod of Huerguolajin’’ (Z.-x. Qiu et al., 1988: fig. 1).

Fig. 6. The lower beds of Aletexire locality, showing two prominent paleosol layers (dark bands).

REMARKS: There are two main exposures at Aletexire. That along the rim of the Tunggur Tableland has a sequence similar to that in the Moergen locality. About 1 km farther north is a large escarpment below the tableland and hidden from view when standing at the tableland rim. This lower exposure consists of reddish brown paleosols and cross-bedded sands at the bottom, a sequence of rock without its equivalent along the northern and western edges of the Tunggur Tableland with the exception of the bottom few meters of the Moergen section. This lower sequence is continuous with the upper sequence, but it apparently had been neglected by previous workers.

The mature paleosols at this locality are not seen elsewhere along the northern and western margins of the tableland. Its stratigraphically lower position in the section suggests a sequence not accounted for elsewhere. Indeed, fossils collected from the overlying sands in the lower beds indicate an assemblage that is more primitive than the classic Tunggur localities. For example, *Stephanocemas* antlers are smaller and less palmate than those from upper beds and they indicate a species more primitive than *S. thomsoni*. The Aletexire section is critical in providing the only link with the southern red bed exposures (Tairum Nor).

IVPP Huerguolajin Locality

GPS LOCATION: 43°47′21.6″N, 113°08′ 23.4″E.

ELEVATION AT TOP OF SECTION: 1030 m.

SYNONYMS: Probably CAE locality ''25 miles northeast of Gur Tung Khara Usu''; IVPP loc. 86021, ''*Platybelodon* Quarry'' (Z.-x. Qiu et al., 1988: fig. 1); and ''1 km northeast to the tripod of Huerguolajin'' (Z.-d. Qiu, 1996: fig. 1).

REMARKS: Several *Platybelodon* skeletons were excavated from this locality by the IVPP team, and hence its name ''*Platybelodon* Quarry'' of 1986 (not the original CAE *Platybelodon* Quarry). Large areas of exposure are present here and we were unable to locate the precise location of the quarry it-

Fig. 7. Exposures at Tairum Nor. Photograph taken near the Roadmark 346 locality looking toward west. Cross-bedded channel sandstones form an erosional bench dividing the red mudstones above and below.

self—the above GPS measurement is thus not an exact reading of the IVPP *Platybelodon* Quarry.

This locality is 23.6 mi (40 km) northeast of the Gulin Huduge, and it may be close, if not equal, to the CAE locality of ''25 miles northeast of Gur Tung Khara Usu''.

IVPP Roadmark 482 Locality

GPS LOCATION: 43°56′10″N, 114°30′00″E (estimate from topographic map).

ELEVATION AT TOP OF SECTION: 1029 m.

SYNONYMS: IVPP loc. 96004; Roadmark 482 Locality (Z.-d. Qiu and Wang, 1999: 124).

REMARKS: Surrounding a small ephemeral pond, this locality is on the south side of the Ho-Xi (Hohhot to Xilinhot) Highway between roadmarks 482 and 483. Located far east of the Tunggur Tableland but in the same trajectory of the northern rim of the tableland, this locality represents the easternmost extent of the Tunggur Formation. Exposed sediments consist of 7 m of red mudstone. This locality is also the only section where a thin (1 m) conglomerate caps the red bed. The disconformably overlying gravel bed produces *Hipparion* tooth fragments and limb bones, and it probably represents the basal gravels of the late Miocene Baogeda Ula Formation (Z.-d. Qiu and Wang, 1999).

AMNH Tairum Nor
(Figure 7)

GPS LOCATION: 43°24′53.4″N, 113°07′06.1″E.

ELEVATION AT TOP OF SECTION: 1037 m.

SYNONYMS: ''S. Camp 1928'' of Osborn and Granger (1932); ''Tairum Nor Basin'' in Dawson (1961: 9) (Tairum, shallow depression in Mongolian; Nor, lake); ''Tairum Nor or Ulan Nor locality'' in Chow and Rozhdestvensky (1960: 5); Roadmark 346 Locality (Z.-d. Qiu and Wang, 1999).

REMARKS: This locality is where the Ho-Xi Highway intercepts the southern margin of the Tunggur Tableland at roadmark 346 (in kilometers). The southern escarpment has the best exposures in the Tunggur Tableland. Continuous badlands can be seen for many kilometers northeast and southwest of the 346 mark. Because of this continuity and consistency of lithological sequence (see below), materials from 3–4 km east or west of the 346 mark are included in this locality.

On 26 July 1928, the CAE team camped near a ‘‘precipitous escarpment’’ on the southern edge of the Tunggur Tableland near a well named Min Gan Usu, which ‘‘fronts the long narrow depression of Tairum Nor’’ (Andrews, 1932: 405). Today, the Ulan Tairum Nor, also known as Haerchabu Nor in the topographic map, is mostly dry grassland except for isolated ponds in wet seasons, and it is approximately 5 km southwest of the 346 locality. The original Min Gan Usu cannot be found, although a topographic high named Mingan Zhamuqin, 10 km west of the Tairum Nor, probably derived its name from this well. The CAE ‘‘South Camp’’, judging from the sketch map by Osborn and Granger (1932: fig. 1), must be in the section of escarpment approximately 5–10 mi west of the 346 roadmark. This ambiguity of location is not as serious, compared to the northern escarpments, because of the continuity of exposures and the uniformity of stratigraphic sequence in the southern escarpment.

Rock sequences near Tairum Nor were described by Spock (1929: fig. 5), from which the holotype of *Platybelodon grangeri* was found. The channel sands sandwiched between the two red beds thin out on either side of the long exposures. This happens about 4 km southwest and 5 km northeast of the 346 mark. Rocks at Tairum Nor consist of a sequence of upper red mudstone, middle channel sandstone, and lower red mudstone. The upper red bed is lighter and more orange, and appears to be more pedogenic in origin with repeated color bands. The lower red bed, on the other hand, is darker red and more uniform (lacking bedding planes) when viewed from the distance.

Z.-d. Qiu and Wang (1999) proposed the Tairum Nor fauna, based on collections from the lower red bed, because of its presence of *Tachyoryctoides*, a survivor from Oligocene and early Miocene, and primitive morphologies in *Atlantoxerus*, *Heterosminthus*, and *Gobicricetodon*. In addition, B.-y. Wang (1988) described from the AMNH Tairum Nor collection a peculiar Ctenodactyloid, *Distylomys tedfordi*, which is not seen elsewhere in the Tunggur Formation. The precise stratigraphic horizon for the AMNH Tairum Nor collection is not clear. However, our own small mammals were mostly screen-washed from the lower red bed, although the upper red beds also produced fossils. The middle channel sandstone mostly produced large mammals. New materials of the primitive hyaenid *Tunguricti*s from calcareous nodules on top of the channel sandstone indicate an individual somewhat smaller than the type skull from Wolf Camp, and they have more slender upper carnassials and less transversely elongated upper molars. These morphological differences may indicate stratigraphic differences, although they may be accounted for by individual variation. Fossils from the sandstone and upper red mudstone include typical *Platybelodon* fauna, but they also share some musteloids with North America: *Leptarctus neimenguensis*, a new species of *Sthenictis*, and a form related to *Aelurocyon* (under study). It is difficult to account for all three of the above carnivores as associated with the particular depositional environment at Tairum Nor (e.g., near stream). Therefore, the absence of these taxa in the northern and western escarpments is interpreted to be due to a lower stratigraphic level at Tairum Nor.

DISTRIBUTION OF TUNGGUR FORMATION

In his original description of the Tunggur Formation, Spock (1929) only described two exposures that were seen in the 1928 field season, namely the stratotype at North Camp and the South Camp at Tairum Nor. After a more extensive exploration in the 1930 field season, Osborn and Granger (1932) were able to publish a map outlining the western part of the Tunggur Tableland, whose escarpment serves as a prominent topographic feature delineating the distribution of the Tunggur Formation. The apparent drawback in equating the Tableland with the Tunggur Formation is the fact that the rim of the Tableland is essentially an erosional feature controlled by resistant rocks such as channel sandstones or marls. The marls are more numerous in the northern and western escarpments where they form resistant hard caps, whereas the southern escarpment follows a continuous channel sandstone that stands out from less resistant red mudstones. No basement rock is exposed along the Tableland rim, and the true extent of the Tunggur Formation (i.e., the original depositional basin) must be considerably larger than is now outlined by the Tableland. Nonetheless, the simple delineation based on the Tableland edges serves well for paleontological investigations since fossils are always found in exposures along the edges, whereas areas of more gradual relief, both on top and below the Tableland, are covered by grasses growing on Pleistocene gravels and sands.

The need for regional stratigraphic correlations by geological survey teams, however, often leads to estimates about the distribution of the Tunggur Formation that are far more extensive than can be justified paleontologically. Therefore, in a comprehensive summary of past surveys recently published by the Bureau of Geology and Mineral Resources of Nei Mongol Autonomous Region (1991), the Tunggur Formation, as a mappable unit, was shown to crop out from 42°00′ to 44°20′ in latitude and 111°30′ to 114°30′ in longitude, a rectangle covering an area of approximately 60,000 km^2, many times larger than that outlined by the Tunggur Tableland. Much of the larger distribution was based on superficial lithostratigraphic characteristics, often simply a gross generalization of ''red bed'', with little or no knowledge about fossils or other means of age control. Such an approach, relying on gross similarities of sedimentary packages, apparently assumes a large, continuous lacustrine basin, an idea that is prevalent in most Chinese geological survey teams dealing with terrestrial sediments. Our own surveys suggest that Neogene terrestrial sediments in central Inner Mongolia are often scattered in small to medium-sized basins. Localities of different ages can be spaced within a few kilometers of each other. For example, the Amuwusu and Shala localities, which were mapped as the southwesternmost exposure of the Tunggur Formation by the regional geological survey (Bureau of Geology and Mineral Resources of Nei Mongol Autonomous Region, 1991), contain vertebrate fossils younger than the Tunggurian land mammal age (Z.-d. Qiu and Wang, 1999).

Problems further arise because of the different interpretations of stratigraphic relationships between the Tunggur Formation and the Baogeda Ula Formation. As discussed above, the regional geological teams proposed a disconformable relationship between the two formations within the Tunggur Tableland. Assuming a southward dip, the Tunggur Formation was shown croping out only along the northern escarpment of the Tableland while the main body of the Tableland, as well as its southern escarpments, were all interpreted to be Baogeda Ula Formation. Such an interpretation contradicts past paleontological studies (CAE, SSPE, IVPP) that consistently regarded the Tunggur Formation as flat lying and containing vertebrate fossils of Tunggurian age only, without any evidence of the presence of a strata containing *Hipparion*. Therefore, although the original distribution of the Tunggur Formation must have been larger than the Tableland, for the purpose of paleontological studies we continue to confine the Tunggur Formation to the Tableland edges (fig. 1).

LITHOSTRATIGRAPHIC CORRELATIONS

Stratigraphic relationships among various exposures in the Tunggur Tableland have not been a primary concern until recently. Spock (1929: figs. 4, 5) illustrated two representative sections, one at the stratotype locality at Mandelin Chabu and the other at the Tairum Nor locality. He did not attempt to correlate these beds and only noted (Spock, 1929: 5) that ''lack of continuity and a pronounced lens-like form are the outstanding characteristics of the beds.'' Both of these characteristics, of course, hinder precise correlations. Such an obstacle is not a problem if one assumes that vertebrate fossils, coming from relatively thin beds, represent a contemporaneous fauna. In practice, the term ''*Platybelodon grangeri* Life Zone'' of Osborn and Granger (1932) serves this purpose, and fossils from the Tunggur Formation have generally been regarded as a single fauna. Z.-d. Qiu (1996), however, demonstrated that this is not the case for small mammals—two distinct assemblages were recognized in Moergen locality, corresponding to what he informally recognized as upper (bed V) and lower members (beds I–IV) of the Tunggur Formation. Precise correlations among various localities of the Tunggur Tableland thus become a matter of some importance to prevent a mixing of faunas.

Z.-x. Qiu et al. (1988: 403) redescribed the Mandelin Chabu section (a few hundred meters east of Spock's original North Camp; the top marl and capping cross-bedded sandstone in Spock's section were not mentioned by Z.-x. Qiu et al.) and regarded the section as typical of the Tunggur Formation that ''holds considerably stable, thus renders no particular difficulty for section-to-section correlation.'' In particular, they singled out the upper red mudstone (bed 4 below) as a marker bed, ''owing to its bright color and little changed thickness.'' This theme was further fleshed out in Z.-d. Qiu (1996: figs. 3, 4), who recognized five distinct beds as characteristic of the Tunggur Formation. As typified from Moergen, these beds are (from bottom to top): (1) variegated mudstone, (2) mostly sandstones, (3) sandy mudstones with large quantity of concretions, (4) brick-red mudstone, and (5) greenish to brownish mudstone and sands. Five measured sections were presented by Z.-d. Qiu (1996: fig. 4), which were correlated on the basis of the above five beds.

Close examinations, however, reveal complexities not previously noted. First, there are widespread marls throughout the northern and western escarpments. These marls, although lenticular in some places, may serve as possible markers in combination with other beds. Secondly, the stability and uniqueness of the brick-red mudstone is questionable. Two of the five sections measured by Z.-d. Qiu (1996: fig. 4) lack this layer (including the CAE *Platybelodon* Quarry and IVPP 86021, two of the most productive localities), whereas others, such as the entire southern escarpment, have more than one red bed. As noted by Spock (1929), the stratigraphy is further complicated by a general lack of lateral continuity between exposures and the lenticular nature of the channel sandstones.

A radically different scheme was proposed by the regional geological survey teams (e.g., Bureau of Geology and Mineral Resources of Nei Mongol Autonomous Region, 1991), in which the Tunggur Formation is only recognized on the northern escarpment of the Tableland, and the Tableland proper was mostly assigned to the overlying Baogeda Ula Formation that crops out in the southern escarpment (see also above). Fundamental to this theme are two assumptions: (1) A southward dip characterizes the entire Tunggur Formation, and (2) the late Miocene Baogeda Ula Formation disconformably overlies the Tunggur Formation and can be correlated with the red beds along the southern escarpment. The Tunggur Formation was thus mapped as a thin strip, exposed only in the northern escarpment of the Tableland. The first assumption cannot be substantiated by us (or any previous workers), and it appears to be based on measurements of cross-bedding in channel sands. The second assumption was derived from the stratotype section of the Baogeda Ula Formation and cannot be supported by our own observations. In fact, based on fossil evidence, the southern exposures are lower, not higher, than the northern ones.

Our present correlation scheme (fig. 8) is primarily based on lithological characteristics. Fossils are taken into consideration only in the Tairum Nor section, which is far from other localities and whose lithological characters are sufficiently different from those elsewhere to make direct lithological correlation difficult. As has been previously summarized (Z.-d. Qiu, 1996; Z.-x. Qiu et al., 1988), exposures along the northern and western escarpments generally consist of a package of channel sandstones (often containing numerous bivalve shell fragments) in the lower part (except the Aletexire section, see below), followed in the middle by mudstones of mostly red or brown, and finish at the top by thin layers of greenish or light gray marls interbedded with greenish or variegated mudstones. Generally less than 40 m in total thickness, this package is here informally termed the upper beds of Tunggur For-

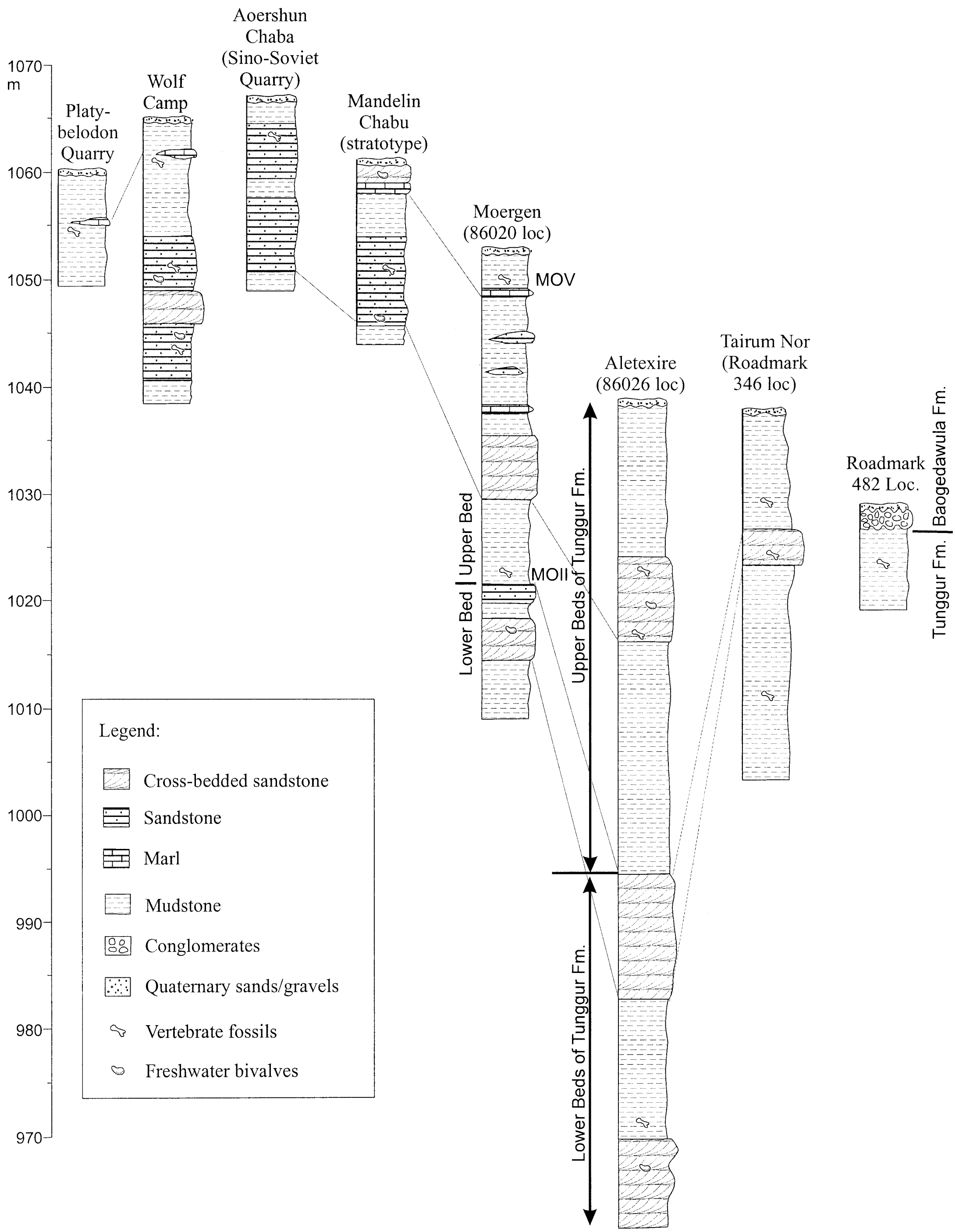


Fig. 8. Representative stratigraphic columns and correlations. From left to right, the columns are arranged from west to east (with the exception of the Tairum Nor section, which spans a long distance from west to east) and the positions of their top gravels correspond to their elevations (scale to the left). MOII and MOV correspond to small mammal horizons at Moergen level II and Moergen level V (Z.-d. Qiu, 1996).

mation (fig. 8). Representing a fining upward sequence, the occurrence of marls near the top, in contrast to abundant channel sands below, seems to indicate a more arid climate. Although serving well as a generalized model of depositional sequence, such a simplified scheme, however, cannot be applied in every section, mostly due to the lenticular nature of the channel sandstones and marls.

The lower beds of the Tunggur Formation, here defined by the lower section of the Aletexire locality (fig. 8) and much of the Tairum Nor section, have traditionally received much less attention because of their lack of abundant fossils. Lithologically, the lower beds are relatively simple and, as typified by the Tairum Nor section, consist of a rather uniform package of red or orange-red mudstone interrupted in the middle by a channel sandstone. Our correlation of the Tairum Nor section with the lower part of the Aletexire section remains speculative. The long distance and lack of intermediate exposures aside, the more mature paleosols at Aletexire have a different appearance from the presumed counterpart at the Tairum Nor section (upper red bed). An obvious implication of such a correlation is that the upper beds of the Tunggur Formation were either eroded away or were never deposited at the southern part of the original Tunggur depositional basin.

MAGNETOSTRATIGRAPHY

Two sections were chosen for paleomagnetic analysis, Moergen and Tairum Nor (346 locality). The Moergen section, sampled in 1995 field season, was selected for its richness in small mammals and the thickness of exposures along the northern margin of the Tunggur Tableland. The main section is located near the western end of the east–westerly-oriented exposure at the Moergen locality, beginning at 43°44′55.0″N, 112°54′02.5″E and ending at 43°44′37.6″N, 112°54′04.3″E. To avoid several meters of loose, coarse-grained sands between two prominent marls, the middle section was laterally shifted 600 m to the east (at 43°44′33.5″N, 112°54′31.3″E), where the exposures consist of fine-grained mudstones. Three segments of various lengths have to be omitted in the sampling due to the presence of a few cross-bedded sands in the lower half of the section.

In contrast to the more varied lithologies in the Moergen section, the section at Tairum Nor was chosen because of its more uniform rock composition of mostly brick-red mudstone with a single layer of cross-bedded sands (less than 3 m in thickness) in the middle. In addition, our discoveries of a small mammal fauna, the Tairum Nor Fauna, which seems to indicate a somewhat older age, constitute an additional reason to sample this locality. Furthermore, some important fossils, such as the holotypes of *Platybelodon grangeri*, *Bellatona forsythmajori*, and *Distylomys tedfordi* were collected from the southern exposures. It is therefore important to learn about the paleomagnetics at the 346 locality, not only as a tool of local correlation but also to place these taxa in chronological perspective. Collected in 1996 field season, the 346 section begins at 43°24′48.3″N, 113°06′57.6″E and ends at 43°24′55.9″N, 113°06′57.8″E.

Oriented hand samples were taken from the Moergen section in 1995 and from the Tairum Nor section in 1996. Sample orientation was measured by geologic compass. Three independent samples were taken in each sampled horizon (sites). All samples were taken from fine-grained mudstones or siltstones in 1-m intervals, except where sediments are too coarse to permit sampling. A total of 90 samples were collected from the Moergen section and 102 from the Tairum Nor section.

The samples were cut into 2 × 2 × 2-cm cubes. The direction of magnetization was measured on a three-axis cryogenic magnetometer in the paleomagnetic laboratory at the University of Florida. All samples were thermally demagnetized in increments of 13–14 steps. Representative plots of thermal demagnetization are shown in figure 9. The demagnetization reveals two magnetic components, a low temperature component that is removed by 100–200°C, whereafter characteristic directions become clearly revealed in trajectories to the origin at temperatures of 670–1000°C.

Seven magnetozones are recognized in Moergen section and six in Tairum Nor section (fig. 10). Correlations with the geomagnetic polarity time scale (Berggren et al., 1995) are difficult because of the relatively short sections and the frequent reversals during the Miocene. Sampling gaps in coarse sandstones in the Moergen section further compromises the reliability of the correlation.

As discussed in the Biochronology section below, the Tunggur faunas are clearly middle Miocene in nature when compared to mammalian faunas from Europe and North America. Within the middle Miocene between 11–16 Ma, the lower and upper parts of the geomagnetic polarity time scale (Berggren et al., 1995) are dominated by relatively long reversed (C5Br and C5r) and normal (C5Bn through C5ACn) magnetozones, in contrast to a distribution of shorter and more temporally equivalent normal and reversed magnetozones in the Tunggur sequence. This leaves C5An.1n through C5ABr as the most suitable segment for correlation. Within this segment, we correlated the composite Tunggur section with the C5Ar.3r through lower part of C5r.3r in approximately 11.8–13 Ma, younger than we had estimated earlier (X. Wang et al., 1996). Such a correlation is consistent with the small mammals, which are comparable to those from European land mammal zones (MN) 7–8 in the late Astaracian (Z.-d. Qiu, 1996), as well as to a number of large carnivorans (see Biochronology below). However, we emphasize the preliminary nature of our magnetic study, which must be tested in additional sections. Based on this correlation, sedimentation rate for the Moergen locality is 63 mm/1000 years (44 m/0.7 m.y.) and for the Tairum Nor locality is 47 mm/1000 years (35 m/0.75 m.y.), with the latter having far fewer channel sandstones than does the former.

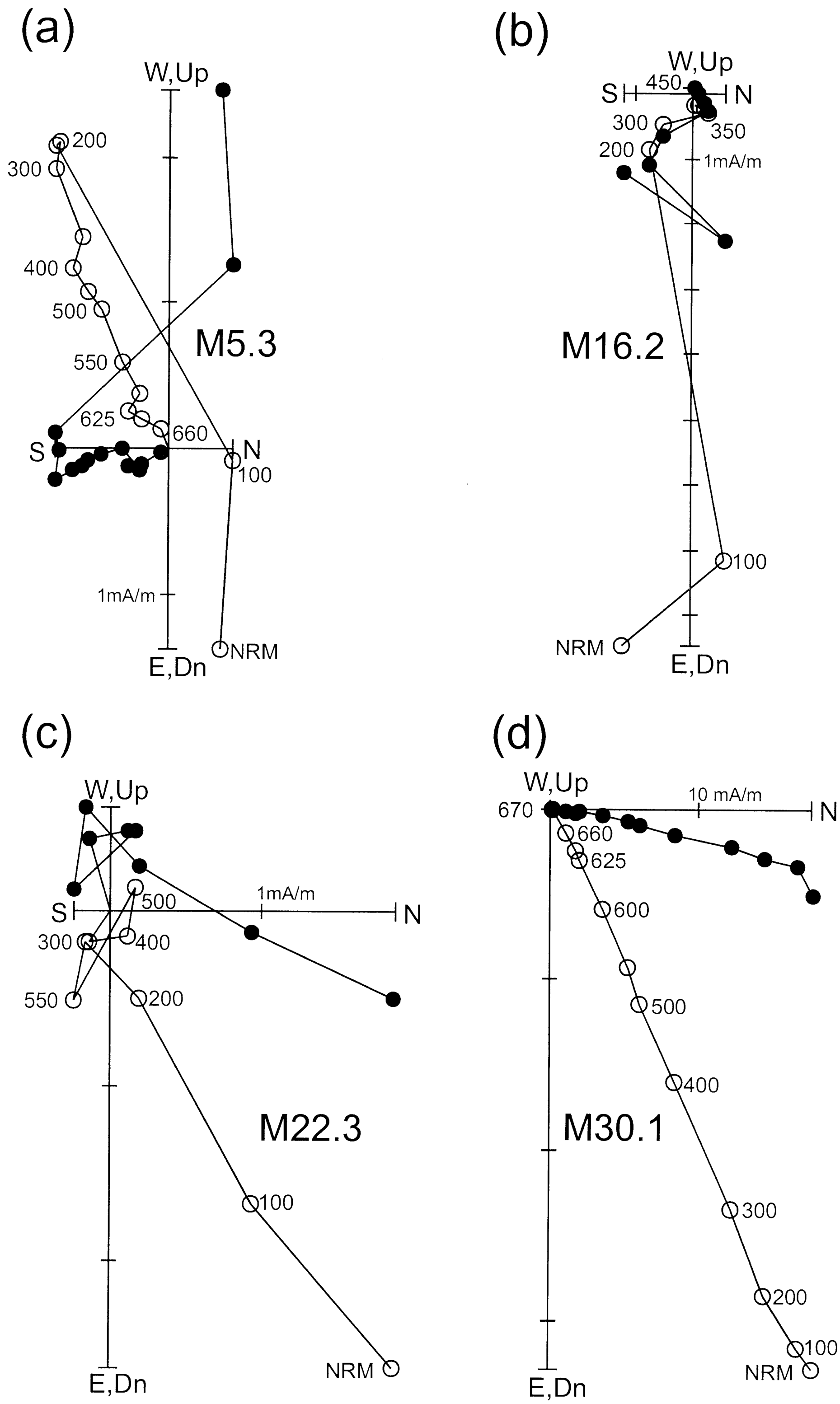
BIOSTRATIGRAPHY

Due to their relatively higher densities in fossil records as well as modern collection methods that provide more precise control of horizons, small mammals are ideally suited for fine-scale regional stratigraphic correlations. Z.-d. Qiu (1996) first discerned some faunal changes within the small mammal sequence in the Moergen (MO) section. At the top of the section (horizon MOV, see fig. 8), small mammals begin to show compositional and morphological differences from the main small mammal quarry (horizon MOII), such as the occurrence of *Ansomys*? and the more advanced status of *Gobicricitodon robustus* and *Plesiodipus progressus*. It is now apparent that the absence of *Ansomys* in Moergen level II is likely due to sampling biases since this aplodontid is also recorded in the lower red bed of Tairum Nor (see below). Based on the magnetic stratigraphy above, these two horizons are approximately 0.5 m.y. apart (fig. 10). However, Z.-d. Qiu did not attempt to establish a new fauna for horizon MOV.

Subsequently, we (Z.-d. Qiu and Wang, 1999) established a new Tairum Nor Fauna to be distinguished from the Moergen Fauna (''Tunggur Fauna'' in that paper) from the northern and western edges of the Tunggur Tableland (except the lower part of the Aletexire section), again based on small mammal records only. The Tairum Nor Fauna is here defined on mammals from the lower red bed and middle sandstones along exposures in Tairum Nor. Here we present complete faunal lists of all localities for these two faunas (table 1), part of which is an update published by Z.-x. Qiu et al. (1988).

Faunal distinctions are recognizable within sections where small mammals are finely sampled. As discussed above, faunal composition and evolutionary changes of individual lineages are observed along the Moergen section (Z.-d. Qiu, 1996). In large mammals, however, since most of them belong to early collections that have inadequate data for precise stratigraphic horizons, further stratigraphic resolution within many of the classic localities is, regrettably, still not possible. Nonetheless, in the case of a recently recognized long section—the Aletexire locality that has the longest exposure (approximately 80 m) among all Tunggur localities—recent attention to finer scale collecting has resulted in hints that further divisions are indeed possible. Among others, a new and more primitive form of *Stephanocemas* appears to be present in the lower beds of this section (under study).

The Tairum Nor locality is another section finely sampled that yields different faunas. The most prominent difference in the small


(a)
W,Up
200
300
400
500
550
625
660
S
N
100
1mA/m
NRM
E,Dn
M5.3
(b)
W,Up
450
S
N
300
350
200
1mA/m
M16.2
100
NRM
E,Dn
(c)
W,Up
1mA/m
S
N
500
300
400
550
200
M22.3
100
NRM
E,Dn
(d)
W,Up
10 mA/m
670
N
660
625
600
500
400
M30.1
300
200
100
NRM
E,Dn

mammals is the presence of *Tachyoryctoides* in the lower red bed of Tairum Nor, which, together with the middle sandstone, forms the basis of the Tairum Nor Fauna. This ctenodactylid rodent is commonly found in the Oligocene and early Miocene of Asia, and its previous latest occurrence is in the early Tunggurian Dingjiaergou local fauna of Tongxin, Ningxia Hui Autonomous Region (Z.-x. Qiu et al., 1999). Its appearance in Tairum Nor thus becomes the latest occurrence of the genus and extends its range into the late middle Miocene.

Compositional differences of large mammals are also observable in the Tairum Nor localities. Several carnivorans are apparently unique in the middle sandstones of the Tairum Nor section: *Leptarctus neimenguensis*, a new form of *Sthenictis*, and a new musteloid possibly related to *Aelurocyon*. Their absence in the classic localities along northern and western edges of the Tableland is conspicuous and cannot be explained in terms of depositional environments—all are from the prominent channel sandstones between the upper and lower red beds, the kind of deposits well represented elsewhere in the Tunggur Tableland. This lends further evidence that the southern section is older than most of the northern and western localities.

BIOCHRONOLOGY

Although the Tunggur strata have historically been considered Pliocene (Spock, 1929) and late Miocene (Colbert, 1939b; Wood, 1936) following the then-prevalent conventions, that the Tunggur fauna is middle Miocene has not been seriously doubted by recent authors (e.g., Li et al., 1984; Z.-x. Qiu, 1990; Z.-x. Qiu and Qiu, 1995; Z.-x. Qiu et al., 1999). Lack of the three-toed horse *Hipparion* in Tunggur clearly indicates an age older than early late Miocene Vallesian when *Hipparion* first appeared in Eurasia. On the other hand, Tunggur fauna cannot be early Miocene given the advanced status of its large mammals (e.g., *Chalicotherium*, *Listriodon*, *Stephanocemas*, *Anchitherium*) and numerous small mammals shared with the European middle Miocene (Z.-d. Qiu, 1996).

Chinese stratigraphic synthesis in recent years has tended to compare the Tunggur local fauna with the European Neogene Mammal Zone 8 (Z.-x. Qiu, 1990; Z.-x. Qiu and Qiu, 1990, 1995) or to equate it to an undivided European MN 7+8 (Z.-d. Qiu, 1996; Z.-x. Qiu et al., 1999), as is the custom in recent compilation of European MN zones (Agustí et al., 2001; Mein, 1999; Sen, 1997; Steininger et al., 1996; Steininger, 1999).

Since recent attention has been mostly focused on long-distance correlations with European faunas, it may be informative to look toward North America for clues of age relationships, as the Tunggur faunas also have some taxa in common with North America. Among large mammals, the following carnivorans are particularly instructive in their first appearances in East Asia and/or in their well-constrained phylogenetic sequences in the continents of their origins.

Leptarctus neimenguensis Zhai, 1964 is most readily identifiable with North American relatives because of its combination of highly unique cranial and dental morphologies. Strong parasagittal crests and a ventral bullar process combined with a highly hypocarnivorous dentition unambiguously link it to its New World relatives. North American leptarctines have a continuous record from early Hemingfordian to late Hemphillian, and nearly a dozen species have been recognized within this period (see recent summaries by Lim, 1999; Lim and Martin, 2001; Lim et al., 2001; Lim and Miao, 2000). Dental evolution in the leptarctines mainly involved increasing size and hypocarnivory, such as transverse widening of P4–M1, increasing size of P4 hypocone and M1 meta-

←

Fig. 9. Orthogonal projections of progressive thermal demagnetization results for four representative samples (M5.3, M16.2, M22.3, M30.1) of Moergen section in Tunggur Formation. Solid circles represent projections onto the horizontal plane and open circles onto the vertical plane. Treatment levels are in degrees Celsius.

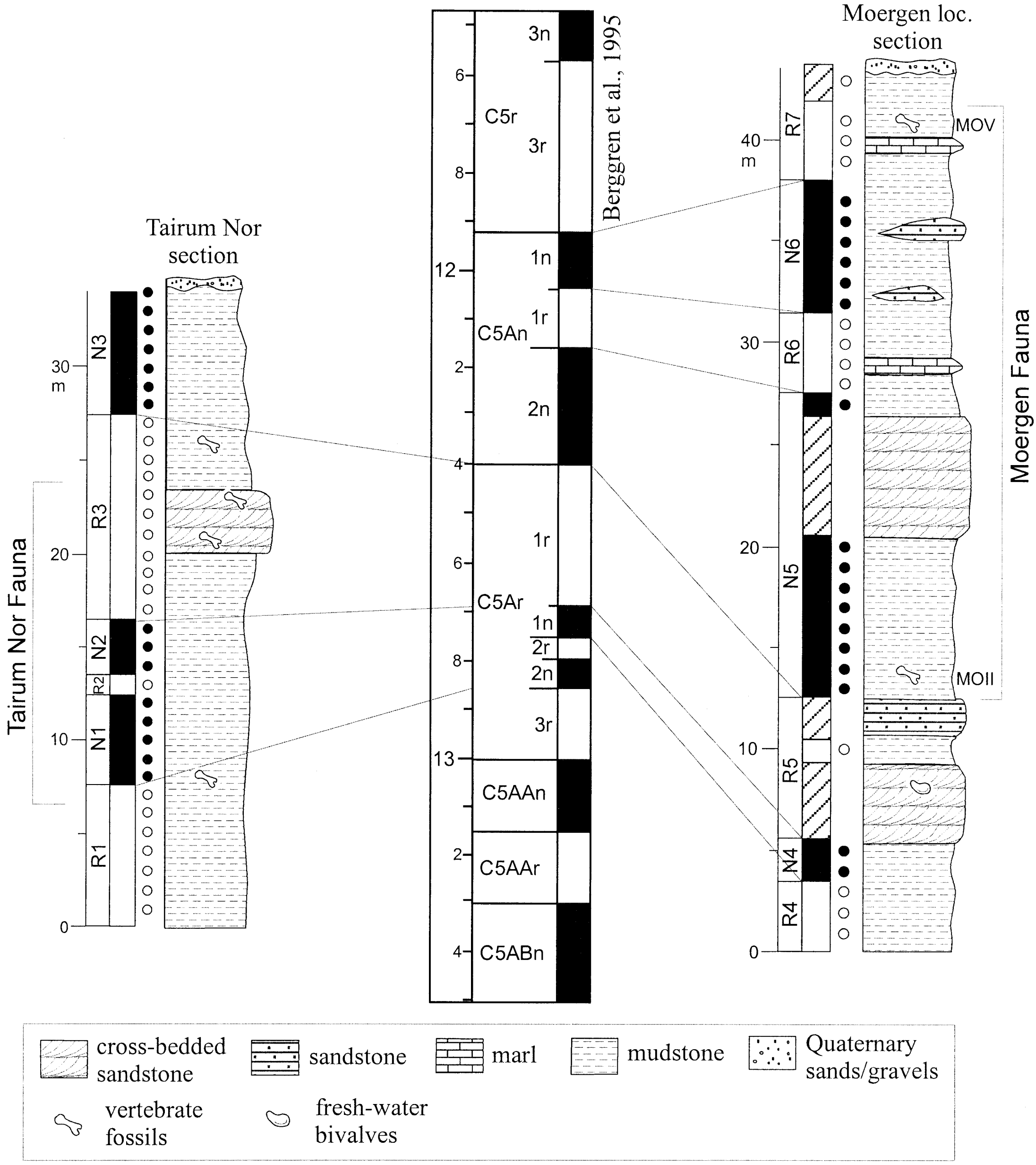


Fig. 10. Magnetostratigraphy of Moergen and Tairum Nor sections. Magnetozones are aligned with the stratigraphic columns. Postulated correlations with the geomagnetic polarity time-scale (Berggren et al., 1995) are indicated by transverse lines. MOII and MOV correspond to small mammal horizons at Moergen level II and Moergen level V (Z.-d. Qiu, 1996).

conule, and development of a parastyle on P4. One can divide known species of *Leptarctus* into primitive and advanced groups based on the above characters. The primitive group includes *L. wortmani*, *L. ancipidens*, *L. primus*, and *L. oregonensis* from the early Hemingfordian to early Barstovian, except *L. primus* which has a longer range into the Clarendonian (Lim, 1999; Lim et al., 2001). Generally they are smaller, lack a P4 para-

TABLE 1

Mammals and Their Occurrences in Different Localities or Stratigraphic Levels of the Tunggur Formation

Locality abbreviations are as follows: 482, IVPP Roadmark 482 locality; AC, SSPE Aoershun Chaba; ALL, IVPP Aletexire lower bed; ALU, AMNH Aletexire upper bed; DA, IVPP Dabuhaer; HU, IVPP Huerguolajin locality; MC, AMNH Mandelin Chabu [= North Camp]; MOII, IVPP Moergen level II; MOV, IVPP Moergen level V; PQ, AMNH *Platybelodon* Quarry; TLR, AMNH Tairum Nor lower red bed; TMS, AMNH Tairum Nor middle sandstone; TUR, AMNH Tairum Nor upper red bed; WC, AMNH Wolf Camp; and ZH, IVPP Zhunwuguer. * Indicates uncertainty in precise stratigraphic level in historical collections.

	Moergen Fauna Localities											Tairum Nor F. Localities		
	PQ	DA	WC	ZH	AC	MC	MOII	MOV	HU	482	ALU	TUR	ALL	TLR	TMS
Insectivora															
Erinaceidae															
Mioechinus? *gobiensis* Qiu, 1996							X	X				X		X	
Mioechinus sp.							X			X					
Erinaceinae gen. et sp. indet.							X								
Talpidae															
Proscapanus sp.							X					X			
Yanshuella sp.							X					X			
Quyania sp.							X								
Desmanella storchi Qiu, 1996							X								
Talpidae gen. et sp. indet.								X							
Soricidae															
Mongolosorex qiui Qiu, 1996							X					X			
Soricinae gen. et sp. indet.							X								
Soricidae gen. et sp. indet.							X					X			
Chiroptera															
Chiroptera gen. et sp. indet.							X								
Rodentia															
Aplodontidae															
Ansomys? sp.								X				X			
Sciuridae															
Eutamias aff. *E. ertemtensis* Qiu, 1991							X	X				X			
Sinotamias primitivus Qiu, 1996							X					X			
Atlantoxerus orientalis Qiu, 1996							X			X		X		X	
Castoridae															
Anchitheriomys tungurensis (Stirton, 1934)									X						X
"*Monosaulax*" *tungurensis* Li, 1964					X	X	X		X						
Hystricops? sp.					X										
Eomyidae															
Leptodontomys lii Qiu, 1996							X					X			
Leptodontomys aff. *L. gansus* Zheng and Li, 1982							X								
Keramidomys fahlbuschi Qiu, 1996							X					X			
Ctenodactylidae															
Tachyoryctoides sp.														X	
Distylomyidae															
Distylomys tedfordi Wang, 1988														X*	
Gliridae															
Microdyromys wuae Qiu, 1996							X					X			
Miodyromys sp.							X								

TABLE 1
(Continued)

	Moergen Fauna Localities												Tairum Nor F. Localities		
	PQ	DA	WC	ZH	AC	MC	MOII	MOV	HU	482	ALU	TUR	ALL	TLR	TMS
Zapodidae															
Heterosminthus orientalis Schaub, 1930 (= *Protalactaga tunggurensis* Wood, 1936)			X				X	X	X	X		X		X	
Dipodidae															
Protalactaga grabaui Young, 1927							X	X		X		X			
Protalactaga major Qiu, 1996							X					X			
Cricetidae															
Gobicricetodon flynni Qiu, 1996							X		X			X		X	
Gobicricetodon robustus Qiu, 1996								X							
Gobicricetodon sp.							X								
Plesiodipus leei Young, 1927 (= *Prosiphneus lupinus* Wood, 1936)			X				X					X		X	
Plesiodipus progressus Qiu, 1996								X							
Megacricetodon sinensis Qiu et al., 1981							X	X		X		X			
Megacricetodon pusillus Qiu, 1996							X	X				X			
Megacricetodon sp.														X	
Democricetodon lindsayi Qiu, 1996							X	X		X					
Democricetodon tongi Qiu, 1996							X	X							
Lagomorpha															
Ochotonidae															
Desmatolagus? moergenensis Qiu, 1996							X			X				X	
Alloptox gobiensis (Young, 1932)							X	X		X		X		X	
Bellatona forsythmajori Dawson, 1961					X		X	X		X		X		X	
Carnivora															
Ursidae															
Plithocyon teilhardi (Colbert, 1939)			X		X										
Pseudarctos sp.											X				
Amphicyonidae															
Amphicyon tairumensis Colbert, 1939											X				
Gobicyon macrognathus Colbert, 1939			X	X											
Mustelidae															
Leptarctus neimenguensis Zhai, 1964															X
Aelurocyon(?) sp.															X
Sthenictis, n. sp.															X
Melodon(?) sp.						X			X						
Mionictis sp.				X											
Martes sp.				X											
Hyaenidae															
Tunguricitis spocki Colbert, 1939			X						X		X				X
Percrocuta tungurensis (Colbert, 1939)			X		X						X				

TABLE 1
(Continued)

	Moergen Fauna Localities												Tairum Nor F. Localities		
	PQ	DA	WC	ZH	AC	MC	MOII	MOV	HU	482	ALU	TUR	ALL	TLR	TMS
Felidae															
Metailurus mongoliensis Colbert, 1939			X						X		X				
Nimravidae															
Sansanosmilus sp.	X										X				
Proboscidea															
Gomphotheriidae															
Serridentinus gobiensis Osborn and Granger, 1932				X											
Platybelodon grangeri (Osborn, 1929)	X	X	X		X	X	X		X						X
Mammutidae															
Zygolophodon sp.									X						
Perissodactyla															
Equidae															
Anchitherium gobiense Colbert, 1939			X		X				X						
Chalicotheriidae															
Chalicotherium brevirostris (Colbert, 1934)			X						X						
Rhinocerotidae															
Acerorhinus zernowi (Borissiak, 1914)			X			X					X				X
Hispanotherium tungurense Cerdeño, 1996	X		X			X									
Rhinocerotidae indet.			X			X									
Artiodactyla															
Suidae															
Listriodon mongoliensis Colbert, 1934			X												
Kubanochoerus sp.									X						
Giraffidae															
Palaeotragus tungurensis Colbert, 1936			X												
Cervidae															
Stephanocemas thomsoni Colbert, 1936		X		X					X		X				
Stephanocemas, n. sp.													X		
Lagomeryx triacuminatus (Colbert, 1936)				X					X						
Euprox grangeri Colbert, 1936									X		X				
Dicrocerus sp.		X				X	X		X		X			X	
Micromeryx sp.		X													
Bovidae															
Turcoceros grangeri Pilgrim, 1934			X								X				
Turcoceros noverca Pilgrim, 1934		X	X	X	X	X	X				X				

style, and have narrow P4–M1 and small hypocones. The advanced group, on the other hand, includes *L.* (*Hypsoparia*) *bozemanensis*, *L. martini*, *L. kansasensis*, *L. progressus*, and *L. supremus* from late Barstovian through late Hemphillian, and commonly feature a larger size, possess a P4 parastyle of various sizes, and have wide P4–M1 and large hypocones. *L. neimenguensis* appears to be a transitional form between the primitive and advanced groups. It is about the same size as *L. primus* and developed a rudimentary P4 parastyle and M1 metaconule. In overall dental morphology, it is best comparable to materials from the late Barstovian to early Clarendonian of Nebraska, for example, the Norden Bridge Quarry (e.g., F:AM 103337) in the Cornell Dam Member and the Burge Quarry in the Burge Member of Valentine Formation. If the above morphological assessment is accurate, the closest North American relative of *L. neimenguensis* is expected to fall within a narrow range of 12.5–13 Ma (based on chronology in Tedford et al., 1987), which is consistent with the magnetostratigraphic correlation above (channel sandstones in the Tairum Nor section in fig. 10).

Similar to the case of *Leptarctus*, a second taxon, *Sthenictis*, n. sp. (under study), whose relatives are found in North America, is also found in the channel sandstones of the Tairum Nor section. *Sthenictis* is widely known in the Hemingfordian through Clarendonian of the Great Plains (Matthew, 1924; Matthew and Gidley, 1904; Peterson, 1910). Although the North American forms generally have wider cheek teeth, the Tunggur *Sthenictis* is best comparable to a specimen from the Burge Quarry (F:AM 25235, an undescribed species) in size and overall morphology, again suggesting an age equivalent to the Barstovian–Clarendonian transition in North America.

Two other large carnivorans are also instructive in age relationships. Although no new material was found for the extremely rare *Sansanosmilus* (Machairodus sp. in Colbert, 1939a), which is represented by a single well-worn upper carnassial from the *Platybelodon* Quarry (''5 miles southwest of Wolf Camp''), this P4 is quite informative relative to the evolution of this barbourofeline carnivoran. The Tunggur *Sansanosmilus* features an upper carnassial with a well-developed parastyle and preparastyle and loss of protocone. Such a combination of features is comparable to that of *S. jourdani* from La Grive-Saint Alban in France and equivalent beds in Europe (Geraads and Güleç, 1997). A direct descendant from the Old World *Sansanosmilus* is the North American *Barbourofelis* (Baskin, 1981; Bryant, 1991; Geraads and Güleç, 1997). The Tunggur *Sansanosmilus* is comparable in stage of evolution to that of early Clarendonian *B. whitfordi*, the earliest and most primitive species in North America, but it is less derived than the late Clarendonian *B. morrisi* from Leptarctus Quarry in Nebraska (e.g., F:AM 79999, holotype) in its less differentiated P4 preparastyle and less reduced P4 protocone root (Geraads and Güleç, 1997; Schultz et al., 1970). The Tunggur *Sansanosmilus* seems to offer the closest example of an ancestral form that gave rise to the New World barbourofelines, and, as such, may slightly predate the North American early Clarendonian first occurrence. A similar comparison can also be made for the Tunggur hemicyonine ursid *Plithocyon teilhardi* (Colbert, 1939a) and its North American counterparts. The latter represents another immigrant event in the early Barstovian (Tedford et al., 1987). Overall, the Tunggur materials are best compared to those from the Burge Quarry (e.g., F:AM 54207) in size and dental morphology.

It thus appears that at least four large carnivorans from Tunggur are either closely related to a North American lineage (*Leptarctus* and *Sthenictis*) or have a comparable stage of evolution in their North American counterparts (*Sansanosmilus*/*Barbourofelis* and *Plithocyon*), all within the narrow range of approximately 12–13 Ma in the latest Barstovian to earliest Clarendonian.

DEPOSITIONAL ENVIRONMENTS

Sediments in the Tunggur Formation have traditionally been interpreted to represent lake or lakeshore deposits with occasional river channels. A large, continuous water body was envisioned by Spock (1929: fig. 6) and Andrews (1932). Such a lacustrine origin of basin history, however, lacks sedimentological support. In general, there are three types of sediments in the Tunggur Formation: cross-bedded sandstones or unconsolidated sands without clear bedding structures, mudstones of various colors with little or no bedding structures and sometimes with calcareous concretions, and freshwater marls. Only the marl may be related to still-water bodies, but these marls are few, quite thin, and usually lenslike in a scale of less than a few hundred meters in lateral extent. There are never more than two marls in a section and their thickness is usually less than one meter, often much less. Furthermore, the marls often taper off laterally within a single section (e.g., at Wolf Camp) and are consistent with a depositional environment of small, high alkaline ponds, as occur in the present day grassland of the region.

Most rocks, however, are sandstones from channel activities or overbank deposits, or brick-red mudstones that have undergone various degree of paleosol development. Channels are present in Tunggur Formation in nearly all sections and tend to form prominent benches that are resistant to erosions. Lenses containing bivalves are always associated with channel sands and are concentrated by postmortem transportation. Individual sets of cross-beds are commonly less than one meter in thickness, indicating limited water depth in the channels. A single channel in the southern escarpment is the most prominent feature of the Tairum Nor exposures. This paleochannel essentially flows along the direction of the Tairum Nor escarpment and apparently controls the appearance of the exposures. Flow direction, as observed on the cross-beddings, is toward the northeast, consistent with the modern topography of the Tableland which shows a generally northeastern dip. Sandwiched between red beds, the channel sandstone is nearly continuous for about 10 km (toward the northeastern end, the channel can be seen to taper off 5.2 km east of the 346 roadmark at 43°27′27.6″N, 113°08′59.5″E). Meandering loops of the channel can be observed in several locations near the 346 roadmark. Here, a single loop can have a radius of 250 m. Approximately 1 km west of the 346 roadmark (43°24′46.7″N, 113°06′31.8″E) the channel banks are exposed, where the channel loops into the outcrop and reemerges a few hundred meters farther west.

Multiple bands of paleosols can be observed in many localities. Distinct bandings of dark and light red mudstones are seen along the southern escarpments, both in upper and lower red beds, and they are also clearly seen in various northern exposures (they are especially clear in the lower section of Aletexire locality). Variable concentrations of calcareous nodules and sometimes root traces are often associated with the paleosols, although some mudstones are quite pure. Vertebrate fossils are sometimes embedded within the nodules, which help to protect the bones. These dark red mudstones with calcareous nodular horizons seem to indicate deposition in a warm semiarid seasonal climate (Hunt et al., 1999).

Unpublished pollen analysis by Dong (1993) at his ‘‘PM-08’’ locality (approximately 44°53′30″N, 113°30′30″E) at the northeast end of the Tunggur Tableland suggests a predominance of trees (54.7–84.1% in total counts of pollen grains) of mixed conifer and broadleaf types. Conifer genera include *Abies*, *Picea*, *Tsuga*, *Keteleeria*, *Cadrus*, and *Pinus*, and broadleaf genera include *Betula*, *Alnus*, *Ulmus*, *Zelkova*, *Celtis*, *Juglans*, *Pterocarya*, *Carya*, and *Quercus*. Shrubs and grasses consist of 5.7–22.6% of grain counts and include taxa such as *Corylus*, *Ephedra*, *Artemisia*, *Polygonum*, *Potamogetox*, Caprifoliaceae, Ranunculaceae, Compositae, Chenopodiaceae, Gramineae, and Umbelliferae. Dong considered the flora of the Tunggur Formation to be characterized by a predominantly mixed forest with small areas of shrubs/grassland.

On the other hand, Z.-d. Qiu’s (1996) study of small mammals suggested a dominance of grassland-adapted species such as hedgehogs (*Mioechinus*), jerboas (dipodids), and picas (ochotonids), and high-crowned, lophodontid cricetids (e.g., *Gobicricetodon* and *Plesiodipus*). Transitional areas do seem to exist as indicated by such taxa as *Eutamias*, *Sinotamias*, *Microdyromys*, *Miodyromys*, and *Heterosminthus*. The aquatic habitat was occupied by beavers (*Anchitheriomys* and ‘‘*Monosaulax*’’), cyprinid fishes, and bivalves. Furthermore, Z.-d. Qiu (1996) suggested a rather dry environment of arid grassland or even semidesert that are associated with such forms as *Atlantoxerus*, *Protalactaga*, and numerous ochotonids, comparable with other north China Tunggurian faunas from the Lanzhou, Tongxin, and Xining basins.

Large mammals, on the other hand, consist of mostly low-crowned browsers, such as *Stephanocemas*, *Listriodon*, *Chalicotherium*, *Anchitherium*, *Palaeotragus*, *Platybelodon*, and *Serridentinus*. There are, however, moderately high-crowned forms, such as *Turcoceros* and rhinos. This is in sharp contrasts to the high-crowned ungulates in the late Miocene Baodean faunas. Colbert (1939b: 7) envisioned the Tunggur environmental setting as follows: ''It would seem probable that the Tung Gur fauna is actually a borderland assemblage, containing forest forms and plains forms intermingled. Evidently these mammals were living on a broad flood-plain, traversed by numerous tree-bordered rivers.''

In summary, the following types of habitats were present in the Tunggur region as indicated by various lines of evidences: mixed forests of conifers and broadleaves (pollens and mammals), shrub or grass plains (pollens and mammals), shallow, meandering rivers (channels, aquatic mammals, fishes, and bivalves), and high-alkaline ponds during periods of dry climates (marls). Such a mixture of diverse habitats is quite different from the present day eastern Inner Mongolia, which is dominated by short-grass prairies, deserts, sand dunes, and high-alkaline ponds under a very dry climate.

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REFERENCES

Agustí, J., L. Cabrera, M. Garcés, W. Krijgsman, O. Oms, and J.M. Parés. 2001. A calibrated mammal scale for the Neogene of western Europe, state of the art. Earth-Science Reviews 52: 247–260.

Andersson, J.G. 1923. Essays on the Cenozoic of northern China. Memoirs of the Geological Survey of China Series A 3: 152.

Andrews, R.C. 1932. The new conquest of Central Asia, a narrative of the explorations of the Central Asiatic Expeditions in Mongolia and China, Natural History of Central Asia. American Museum of Natural History 1: 1–678.

Baskin, J.A. 1981. *Barbourofelis* (Nimravidae) and *Nimravides* (Felidae), with a description of two new species from the late Miocene of Florida. Journal of Mammalogy 62(1): 122–139.

Berggren, W.A., D.V. Kent, C.C. Swisher III, and M.-P. Aubry. 1995. A revised Cenozoic geochronology and chronostratigraphy. *In* W.A. Berggren, D.V. Kent, M.-P. Aubry, and J. Hardenbol (editors), Geochronology, time scales and global stratigraphic correlations: a unified temporal framework for a historical geology. Society for Sedimentary Geology Special Publication: 129–212. Tulsa: Society for Sedimentary Geology.

Bryant, H.N. 1991. Phylogenetic relationships and systematics of the Nimravidae (Carnivora). Journal of Mammalogy 72: 56–78.

Bureau of Geology and Mineral Resources of Nei Mongol Autonomous Region. 1991. Regional geology of Nei Mongol (Inner Mongolia) Autonomous Region, Geological Memoirs Series 1: 1–725. Beijing: Geological Publishing House.

Cartographic Bureau of People's Liberation Army. 1972. Topographic map of Xilin Gol area (1:100,000).

Cerdeño, E. 1996. Rhinocerotidae from the middle Miocene of the Tung-gur Formation, Inner Mongolia (China). American Museum Novitates 3184: 1–43.

Chow, M.-c., and A.K. Rozhdestvensky. 1960. Exploration in Inner Mongolia—a preliminary account of the 1959 field work of the Sino-Soviet Paleontological Expedition (SSPE). Vertebrata PalAsiatica 4: 1–10.

Colbert, E.H. 1934a. Chalicotheres from Mongolia and China in the American Museum. Bulletin of the American Museum of Natural History 67: 353–387.

Colbert, E.H. 1934b. An upper Miocene suid from the Gobi Desert. American Museum Novitates 690: 1–7.

Colbert, E.H. 1936a. *Palaeotragus* in the Tung Gur Formation of Mongolia. American Museum Novitates 874: 1–17.

Colbert, E.H. 1936b. Tertiary deer discovered by the American Museum Asiatic Expeditions. American Museum Novitates 856: 1–21.

Colbert, E.H. 1939a. Carnivora of the Tung Gur Formation of Mongolia. Bulletin of the American Museum of Natural History 76: 47–81.

Colbert, E.H. 1939b. A new Anchitheriine horse from the Tung Gur Formation of Mongolia. American Museum Novitates 1019: 1–9.

Colbert, E.H. 1940. Some cervid teeth from the Tung Gur Formation of Mongolia, and additional notes on the genera *Stephanocemas* and *Lagomeryx*. American Museum Novitates 1062: 1–6.

Dawson, M.R. 1961. On two ochotonids (Mammalia, Lagomorpha) from the later Tertiary of Inner Mongolia. American Museum Novitates 2061: 1–15.

Dong, M.-x. 1993. The study of the Tung-gur Miocene and its mammalian fauna in Sunite Zhouqi of Inner Mongolia. Master's thesis, China University of Geosciences, Beijing.

Dong, M.-x. 1999. Footprints of artiodactyles in Tunggur, Nei Mongol. Vertebrata PalAsiatica 37: 326–329.

Dong, M.-x., and L. Ai. 2001. The lower part of Tunggur Formation and the age of its underlying stratum. *In* T. Deng and Y. Wang (editors), Proceedings of the Eighth Annual Meeting of the Chinese Society of Vertebrate Paleontolgy: 83–90. Beijing: China Ocean Press.

Editorial Committee of Stratigraphic Table of Inner Mongolia Autonomous Region. 1978. Regional stratigraphic table of north China: Inner Mongolia Autonomous Region. Beijing: Geology Press.

Geraads, D., and E. Güleç. 1997. Relationships of *Barbourofelis piveteaui* (Ozansoy, 1965), a late Miocene nimravid (Carnivora, Mammalia) from central Turkey. Journal of Vertebrate Paleontology 17(2): 370–375.

Hunt, R.M., Jr., and N. Solounias. 1991. Evolution of the aeluroid Carnivora: hyaenid affinities of the Miocene carnivoran *Tunguricitis spocki* from Inner Mongolia. American Museum Novitates 3030: 1–25.

Hunt, R.M., Jr., J.B. Swinehart, and X. Wang. 1999. Preliminary geological reconnaissance of the middle Miocene Tung Gur Formation, Inner Mongolia. Proceedings of the Nebraska Academy of Sciences 109: 74.

Li, C.-k. 1963. A new species of *Monosaulax* from Tung Gur Miocene, Inner Mongolia. Vertebrata PalAsiatica 7: 240–244.

Li, C.-k., W.-y. Wu, and Z.-d. Qiu. 1984. Chinese Neogene: subdivision and correlation [in Chinese, English abstract]. Vertebrata PalAsiatica 22: 163–178.

Lim, J.-D. 1999. Systematics and functional morphology of Leptarctus (Mammalia: Mustelidae). Ph.D. dissertation, University of Kansas, Lawrence, 151 pp.

Lim, J.-D., and L.D. Martin. 2001. A new species of *Leptarctus* (Mustelidae) from the Miocene of Kansas, USA. Neues Jahrbuch für Geologie und Paläontologie Abhandlungen 2001(10): 633–640.

Lim, J.-D., L.D. Martin, and R.W. Wilson. 2001. A new species of *Leptarctus* (Carnivora, Mustelidae) from the late Miocene of Texas. Journal of Paleontology 75(5): 1043–1046.

Lim, J.-D., and D.-s. Miao. 2000. New species of *Leptarctus* (Carnivora, Mustelidae) from the Miocene of Nebraska, USA. Vertebrata PalAsiatica 38(1): 52–57.

Lin, C.-s., K. Eriksson, S.-t. Li, Y.-x. Wan, J.-y. Ren, and Y.-m. Zhang. 2001. Sequence architecture, depositional systems, and controls on development of lacustrine basin fills in part of the Erlian basin, northeastern China. American Association of Petroleum Geologists Bulletin 85(11): 2017–2043.

Liu, J.-q. 1999. Volcanos of China. Beijing: Science Press, 219 pp.
Matthew, W.D. 1924. Third contribution to the Snake Creek fauna. Bulletin of the American Museum of Natural History 50: 59–210.
Matthew, W.D., and G.W. Gidley. 1904. New or little known mammals from the Miocene of South Dakota, American Museum Expedition of 1903. Bulletin of the American Museum of Natural History 20: 241–268.
Mein, P. 1999. European Miocene mammal biochronology. *In* G.E. Rössner and K. Heissig (editors), The Miocene land mammals of Europe: 25–38. München: Dr. Friedrich Pfeil.
Meng, J., B.-y. Wang, and Z.-q. Bai. 1996. A new middle Tertiary mammalian locality from Sunitezuoqi, Nei Mongol. Vertebrata PalAsiatica 34(4): 297–304.
Osborn, H.F. 1929. The revival of central Asiatic life. Natural History 29: 2–16.
Osborn, H.F., and W. Granger. 1931. The shovel-tuskers, Amebelodontinae, of Central Asia. American Museum Novitates 470: 1–12.
Osborn, H.F., and W. Granger. 1932. *Platybelodon grangeri*, three growth stages, and a new serridentine from Mongolia. American Museum Novitates 537: 1–13.
Peterson, O.A. 1910. Description of new carnivores from the Miocene of western Nebraska. Memoirs of Carnegie Museum 4: 205–278.
Pilgrim, G.E. 1934. Two new species of sheep-like antelope from the Miocene of Mongolia. American Museum Novitates 716: 1–29.
Qiu, Z.-d. 1996. Middle Miocene micromammalian fauna from Tunggur, Nei Mongol. Beijing: Academic Press, 216 pp.
Qiu, Z.-d., and X. Wang. 1999. Small mammal faunas and their ages in Miocene of central Nei Mongol (Inner Mongolia). Vertebrata PalAsiatica 37(2): 120–139.
Qiu, Z.-x. 1990. The Chinese Neogene mammalian biochronology—its correlation with the European Neogene mammalian zonation. *In* E.H. Lindsay, V. Fahlbusch, and P. Mein (editors), European Neogene mammal chronology: 527–556. New York: Plenum Press.
Qiu, Z.-x., and Z.-d. Qiu. 1990. The sequence and division of mammalian local faunas in the Neogene of China. Journal of Stratigraphy 14: 241–260.
Qiu, Z.-x., and Z.-d. Qiu. 1995. Chronological sequence and subdivision of Chinese Neogene mammalian faunas. Palaeogeography Palaeoclimatology Palaeoecology 116: 41–70.
Qiu, Z.-x., W.-y. Wu, and Z.-d. Qiu. 1999. Miocene mammal faunal sequences of China: palaeozoogeography and Eurasian relationships. *In* G.E. Rössner and K. Heissig (editors), The Miocene land mammals of Europe: 443–472. Munich: Dr. Driedrich Pfeil.
Qiu, Z.-x., D.-f. Yan, G.-f. Chen, and Z.-d. Qiu. 1988. Preliminary report on the field work in 1986 at Tung-gur, Nei Mongol. Chinese Science Bulletin (Kexue Tongbao) 33: 399–404.
Schultz, C.B., M.R. Schultz, and L.D. Martin. 1970. A new tribe of saber-toothed cats (Barbourofelini) from the Pliocene of North America. Bulletin of the University of Nebraska State Museum 9(1): 1–31.
Sen, S. 1997. Magnetostratigraphic calibration of the European Neogene mammal chronology. Palaeogeography Palaeoclimatology Palaeoecology 133: 181–204.
Spock, L.E. 1929. Pliocene beds of the Iren Gobi. American Museum Novitates 394: 1–8.
Steininger, F., W.A. Berggren, D.V. Kent, R.L. Bernor, S. Sen, and J. Agustí. 1996. Circum-Mediterranean Neogene (Miocene and Pliocene) marine-continental chronologic correlations of European mammal units. *In* R.L. Bernor, V. Fahlbusch, and H.-W. Mittmann (editors), The evolution of western Eurasian Neogene mammal faunas: 7–46. New York: Columbia University Press.
Steininger, F.F. 1999. Chronostratigraphy, geochronology and biochronology of the Miocene ''European Land Mammal Mega-Zone'' (ELMMZ) and the Miocene ''Mammal-Zones (MN-Zones)''. *In* G.E. Rössner and K. Heissig (editors), The Miocene land mammals of Europe: 9–24. Munich: Dr. Friedrich Pfeil.
Stirton, R.A. 1934. A new species of *Amblycastor* from the *Platybelodon* beds, Tung Gur Formation, of Mongolia. American Museum Novitates 694: 1–4.
Tedford, R.H., T. Galusha, M.F. Skinner, B.E. Taylor, R.W. Fields, J.R. Macdonald, J.M. Rensberger, S.D. Webb, and D.P. Whistler. 1987. Faunal succession and biochronology of the Arikareean through Hemphillian interval (Late Oligocene through earliest Miocene epochs) in North America. *In* M.O. Woodburne (editor), Cenozoic mammals of North America, geochronology and biostratigraphy: 153–210. Berkeley: University of California Press.
Teilhard de Chardin, P. 1926a. Déscription de mammifères Tertiaires de Chine et de Mongolie. Annales de Paléontologie 15: 1–52.
Teilhard de Chardin, P. 1926b. Étude géologique sur la région du Dalai-Noor. Mémoirs de la Société Géologique de France 7: 1–56.
Wang, B.-y. 1988. Distylomyidae fam. nov. (?Ctenodactyloidea, Rodentia) from Nei Mongol, China. Vertebrata PalAsiatica 26: 35–49.
Wang, X., Z.-d. Qiu, and J. Meng. 1996. Revis-

iting the Tunggur Formation (middle Miocene), Inner Mongolia, and a study of its magneto- and biostratigraphy. Journal of Vertebrate Paleontology 16(3, suppl.): 71A.

Whitford-Stark, J.L. 1987. A survey of Cenozoic volcanism on mainland Asia. Geological Society of America Special Paper 213: 1–74.

Wood, A.E. 1936. Two new rodents from the Miocene of Mongolia. American Museum Novitates 865: 1–7.

Young, C.C. 1932. On a new ochotonid from north Suiyuan. Bulletin of the Geological Society of China 11: 255–258.

Zhai, R.-j. 1964. *Leptarctus* and other Carnivora from the Tung Gur Formation, Inner Mongolia. Vertebrata PalAsiatica 8: 18–32.

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