Sequence of the Cenozoic Mammalian Faunas of the Linxia Basin in Gansu, China

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Abstract In the Linxia Basin on the northeast margin of the Tibetan Plateau, the Cenozoic strata are very thick and well exposed. Abundant mammalian fossils are discovered in the deposits from the Late Oligocene to the Early Pleistocene. The *Dzungariotherium* fauna comes from the sandstones of the Jiaozigou Formation, including many representative Late Oligocene taxa. The *Platybelodon* fauna comes from the sandstones of the Dongxiang Formation and the conglomerates of the Laogou Formation, and its fossils are typical Middle Miocene forms, such as *Hemicyon*, *Amphicyon*, *Platybelodon*, *Choerolophodon*, *Anchitherium*, and *Hispanotherium*. The *Hipparion* fauna comes from the red clay of the Liushu and Hewangjia Formations, and its fossils can be distinctly divided into four levels, including three Late Miocene levels and one Early Pliocene level. In the Linxia Basin, the *Hipparion* fauna has the richest mammalian fossils. The *Equus* fauna comes from the Wucheng Loess, and it is slightly older than that of the classical Early Pleistocene Niheuan Fauna. The mammalian faunas from the Linxia Basin provide the reliable evidence to divide the Cenozoic strata of this basin and correlate them with European mammalian sequence.

Key words: Linxia Basin, Cenozoic, stratigraphy, mammalian fossil, Gansu, China

1 Introduction

The Linxia Basin is situated in the southeastern part of Gansu Province, China, and it is a flexural basin bounded by the Leijishan fault, North Qinling fault, and the Maxian Mountain (Fang et al., 2003). The lithology and structures of the strata in the Linxia Basin are very close to those in a number of Cenozoic sedimentary basins in central Gansu. All of these small basins are called by a joint name, Longzhong Basin. The Cenozoic strata are very thick and well exposed in the Linxia Basin, with a consecutive sedimentary sequence from the Oligocene to the Holocene. More importantly, these deposits contain abundant mammalian fossils, which provide the reliable evidence to divide and correlate the Cenozoic strata of the Linxia Basin (Fig. 1). However, the understanding for the stratigraphical sequence and age had a lot of contradictions previously, with repeated lithologic names and confused fossil evidence. In the field work of the recent years, we cleaned up the sedimentary sequence in order, and determined again the corresponding geological age of each lithologic unit on the basis of the sufficient evidence of mammalian fossils (Table 1). In the Linxia Basin, the Late Oligocene *Dzungariotherium* fauna, the Middle Miocene *Platybelodon* fauna, the Late Miocene *Hipparion* fauna, and the Early Pleistocene *Equus* fauna are the most abundant.

2 Late Oligocene *Dzungariotherium* fauna

The *Dzungariotherium* fauna of the Linxia Basin comes from the sandstones of the Late Oligocene Jiaozigou Formation (Fig. 2). Qiu et al. (1990) reported the mammalian fossils discovered from Jiaozigou in Dongxiang County, and this fauna included *Gomphotherium* sp., *Dzungariotherium* orgosense, Rhinocerotidae gen. et sp. indet., and *Paraelodontid macrognathus*. But the proboscidean fossil (*Gomphotherium*) is proved to interfuse into the Jiaozigou Fauna. The newly discovered taxa also include *Tsaganomys* sp., *Allacerops* sp., *Aprotodon* sp. and *Schizotherium* sp., and originally Rhinocerotidae gen. et sp. indet. is determined to be *Ronzotherium* sp.

The giant rhinoceros is a representative mammal in Asia, and infrequently discovered in Eastern Europe. The giant rhinoceros was diversified in the middle Oligocene, and it became very advanced in the Late Oligocene. *Dzungariotherium orgosense* was first found from the Junggar Basin in Xinjiang, with a large size, rudimental lower incisors, well-developed antecrochets, and wide foot bones. In Xinjiang, *D. orgosense* coexists with *Lophimeryx*, and the last record of the latter is from the middle late Stampian Age in Europe (Qiu et al., 1990). *Allacerops* was a rhinocerotid form living in the Oligocene of Asia, and it was found from the Oligocene in the
Lanzhou Basin adjacent to the Linxia Basin (Qiu and Wang, 1999). Schizotherium was also a characteristic Oligocene form in China, and it was found from the Oligocene Nanpoping Fauna in the Lanzhou Basin (Qiu et al., 1998). Aprotodon was previously found only from Pakistan, Kazakhstan, and the Lanzhou Basin, and it coexisted with the giant rhinoceroses in these three regions (Qiu and Xie, 1997) like in the Jiaozigou Formation of the Linxia Basin. Ronzotherium was found only in the Oligocene of Eurasia (Heissig, 1969). The entelodont was the most diversified during the Santonian and the early-middle Stampian Ages, and Parantelodon macrognathus was very abundant in the Jiaozigou Fauna. Tsaganomys appeared first in the late Early Oligocene, and its assured record ended in the early Late Oligocene. As a result, Tsaganomys is one of the index fossils for the Asian Oligocene (Wang, 2001). Tsaganomys was found from the Oligocene Nanpoping Fauna in the Lanzhou Basin.

Table 1 Divisions of the Cenozoic strata in the Linxia Basin

<table>
<thead>
<tr>
<th>GPIB, 1965</th>
<th>Xie, 1991</th>
<th>Li et al., 1995</th>
<th>Present paper</th>
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<td>Q1</td>
<td>Clayey</td>
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<td>N2</td>
<td>4th M., Linxia Fm.</td>
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<td>Linxia Fm.</td>
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<td>3rd M., Linxia Fm.</td>
<td>N1</td>
<td>Dongxiang Bed</td>
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<td>2nd M., Linxia Fm.</td>
<td>N1</td>
<td>Jiaozigou Fm.</td>
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<td></td>
<td>1st M., Linxia Fm.</td>
<td>N1</td>
<td>Shanghuang Fm.</td>
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Apparently, the age of the Jiaozigou Fauna is Late Oligocene.

3 Middle Miocene Platypelodon fauna

The Platypelodon fauna of the Linxia Basin is represented by the Laogou locality in Hezheng County, mainly from the conglomerates of the late Middle Miocene Laogou Formation, and two sandstone fossil beds of the early Middle Miocene Dongxiang Formation at Dalanggou and Wangshijie in Guanghe County are combined into the Laogou Fauna (Fig. 2). This fauna includes Alloptox sp., A. minor, Megacricetodon sinensis, Protalactaga tungurensis, Saymys cf. obliquidens, Pliopithecus sp., Hemicyon teihardii, Amphicyon tairumensis, Gobicyon sp., Pterocrocuta tungurensis, Pseudaelurus guangheensis, Choerolopodan sp., Gomphotherium sp., Platypelodon grangeri, Zygolophodon sp., Anchitherium gobienisi, Alicornops sp., Hispanotherium mattricense, Calicotherium sp., Kubanochoerus gigas, Listriodon mongoliensis, Dorcatherium sp., Moschus sp., Palaeotragus tunguensis, and Turcocerus sp. (Guan, 1988; Deng, 2003).

The fossils of the Laogou Fauna are the typical Middle Miocene forms, represented by Tunggurian Platypelodon and Anchitherium (Qiu and Qiu, 1995). The shared genera between the Laogou and Tunggur Faunas include Alloptox, Hemicyon, Amphicyon, Platypelodon, Zygolophodon, Anchitherium, Hispanotherium, Kubanochoerus, Listriodon, Palaeotragus, and Turcocerus. Alloptox was widespread found from the Middle Miocene faunas in China, such as Tunggur in Inner Mongolia (Young, 1932), Lengshuigou in Lantian, Shaanxi (Li, 1978), Qijia in Minhe, Qinghai (Qiu et al., 1981), and Dingjia’ergou in Tongxin, Ningxia (Wu et al., 1991). Pliopithecus existed during MN5-9 in Europe, and it was found from the Dingjia’ergou and Halamagai (Junggar, Xinjiang) Faunas of the Middle Miocene in China (Qiu and Guan, 1986; Wu
et al., 2003). In Eurasia, *Hispanotherium matri tense* was found in Spain, Portugal and France of Europe, and Turkey, Pakistan, Mongolia and China of Asia. In China, *H. matri tense* distributed widespread, found from the Middle Miocene Dingjia’ergou, Lengshuigou and Erlanggang (Fangxian, Hubei) Faunas (Zhai, 1978; Yan, 1979; Guan, 1988). *H. matri tense* is smaller than *H. tungurense* of the Tunggur Fauna (Cerdeño, 1996; Deng, 2003). *Alicornops* distributed widespread in Europe during MN6-10 (Cerdeño and Sánchez, 2000), and it was found from the Middle Miocene strata in Turkey (Heissig, 1976). *Kubanochoerus* appeared in the strata of MN6 in Caucasia, and it was found at Dingjia’ergou, Tunggur and Koujiacun (Lantian, Shaanxi). Therefore, *Kubanochoerus* is a typical Middle Miocene form.

4 Late Miocene-Early Pliocene *Hipparion* fauna

Qiu et al. (1987b, 1988, 1991) described the Late Miocene mammalian fossils discovered from the Linxia Basin, including *Dinocrocuta gigantea, Agriotherium inexpetans, Hipparion* sp., *Acerorhinus hezhengensis, Chilotherium* sp., *Cervavitus* sp., and *Honanotherium* sp. Since recent years, we have found more abundant fossils of the *Hipparion* fauna from the red clay of the Late Miocene.
Liushu Formation and the Early Pliocene Hewangia Formation. These fossils can be distinctly divided into four levels, represented by Guonigou (Dongxiang County), Dashengou (Hezheng County), Yangjiashan (Hezheng County), and Shilidun (Guanghe County) respectively (Fig. 2).

4.1 Guonigou Fauna

The Guonigou Fauna comes from the lower part of the Liushu Formation, and its fossils include Dinocrocuta gigantea, Machairodus sp., Tetrarophodon sp., Hipparion dongxiangense, Parelasmotherium simplum, P. linxiaense, and Shaanxispira sp.

The Guonigou Fauna is characteristic of early Late Miocene age. Dinocrocuta gigantea is a representative of the early Hipparion fauna in Asia, and it is discovered mainly from the early Late Miocene, corresponding to the European Vallesian Age or MN9-10 (Howell and Peter, 1985). The materials discovered in China show the same trend. The fossils of Dinocrocuta were found from Bahe in Lantian, Shaanxi (Liu et al., 1978; Zhang et al., 2002) and Bulong in Biru, Tibet (Zheng, 1980), and they came from strata corresponding to the Vallesian (Li et al., 1984; Qiu and Qiu, 1995). Dinocrocuta was also reported from Songshan in Tianshu, Gansu (Zheng, 1982) and Laogaochuan in Fugu, Shaanxi (Xue et al., 1995; Zhang and Xue, 1996), and the two localities were considered to be equivalent to the European Turolian Age. However, the specimens of the former came from a drug store, and the age of the latter need further studies. The size of H. dongxiangense is smaller than that of H. parvum, the smallest known species of Hipparion in China, and its characteristic structures of the hypocone and the hypocone groove frequently occur among the Middle Miocene hipparionines from North America, but are infrequent among the late hipparionines. As a result, H. dongxiangense indicates an earlier age (Qiu and Xie, 1998). Parelasmotherium is more primitive than Sinootherium, the representative taxon in the Baode Fauna, and the former is the earliest member of the giant elasmotheres developing toward hypsodont teeth (Qiu and Xie, 1998; Deng, 2001c). Shaanxispira also appeared in the Bahe Fauna (Liu et al., 1978; Zhang et al., 2002). Consequently, the age of the Guonigou Fauna should be early Late Miocene, corresponding to the Vallesian Age of the European. According to this correlation, the Qaidam Fauna (Bohlin, 1937) may have the same evolutionary level with the Guonigou Fauna (Qiu and Qiu, 1995; Qiu et al., 1999). However, both faunas do not have many taxa, and the shared genera include only Tetrarophodon and Hipparion, whose materials are too rare to be certain about their specific status.

4.2 Dashengou Fauna

The Dashengou Fauna comes from the middle part of the Liushu Formation. Qiu et al. (1987b, 1988, 2000) described Acerorhinus hezhengensis, Dinocrocuta gigantea, and Hezhengia bohlini in the Dashengou Fauna, and other taxa include Pararhizomys hipparionum, Promephitis sp., P. hootoni, Melodon majori, Sinictis sp., Ictitherium sp., Hyenaictitherium wongii, H. hyaenoides, Machairodus palanderi, Felis sp., Tetrarophodon exoletus, Hipparion chiai, H. weihongensis, Chilootherium wimin, Iranootherium morgani, Chleuastochoerus stehlini, Dicrocerus sp., Samotherium sp., Honanotherium schlossei, Gazella sp., and Miotragocerus sp.

The Dashengou fauna is still composed of early Late Miocene taxa, such as Dinocrocuta gigantea, which first appeared in the Guonigou Fauna. Other important components of the Bahe Fauna are relatively richly represented in the Dashengou Fauna, such as Hipparion weihongensis and H. chiai. These two species of Hipparion have a large size, deep preorbital fossae far from the orbit, and narrow and long protocones. These characters show that both of them apparently belong to the H. primigenius group, and the hipparionines of this group in Europe and Africa are predominantly Vallesian in age (Qiu et al., 1987a). The shared species in the Bahe and Dashengou Faunas also include Tetrarophodon exoletus and Chleuastochoerus stehlini (Liu et al., 1978). Hezhengia bohlini is one of the most typical taxa in the Dashengou Fauna. The horncores of Hezhengia are obviously less specialized than those of the middle-late Late Miocene ovibovines, such as Plesiaddax, and its premolars are relatively long, with strong ribs and styles. Therefore, the primitive characters of H. bohlini imply that its age should be earlier than that of the middle-late Late Miocene ovibovines (Qiu et al., 2000). Acerorhinus hezhengensis has a very narrow mandibular symphysis and little separated parietal crests to form a high sagittal crest, and thus it is close to A. tsaidamensis in the Qaidam Fauna but different from A. palaeosinensis in the Baode Fauna (Qiu et al., 1987b). Judging from the whole components of the Dashengou Fauna, it should be correlated to the late Vallesian Age of Europe. Besides the Bahe Fauna, the Lamagou Fauna in Fugu, Shaanxi (Xue et al., 1995) may be contemporaneous with the Dashengou Fauna. There are many common taxa between the Lamagou and Dashengou Faunas, including Dinocrocuta gigantea, Hyenaictitherium wongii, Hipparion chiai, Chilootherium wimin, Samotherium sp., and Miotragocerus sp. Moreover, Acerorhinus fuguensis from Lamagou also is very close to A. hezhengensis from the Dashengou Fauna (Deng, 2000).
4.3 Yangjiashan Fauna


In the Yangjiashan Fauna, the early Late Miocene representatives, such as *Dinocrocuta gigantea* and *Hezengia bohlini* have disappeared. The Yangjiashan Fauna is similar to the Baode Fauna, the typical fauna of the late Late Miocene in China. They share many taxa, including *Simocyon* sp., *Plesiogulo* sp., *Parataxidea sinensis*, *Promephitis hootoni*, *Hyaenictitherium wongii*, *H. hyaenoides*, *Adercota variabilis*, *Machaouras* sp., *Metalurus* minor, *Dicerorhinus ringstomi*, *Chleuastochoerus stehlini*, *Microstonyx major*, *Cervivitus novorossiae*, *Palaeotragus microdon*, *Honanotherium schlosseri*, and *Sinotragus* sp. Like the Baode fauna, rhinocerotids are absolutely dominant in the Yangjiashan Fauna, although both of them are named as the *Hipparion* faunas. On the other hand, the more primitive *Chilotherium wimani* in the Yangjiashan Fauna is replaced by the more derived *C. anderssoni* in the Baode Fauna. The primitive characters of *C. wimani* include the low position of orbit, well-developed supraorbital tubercle, weak postorbital process, concave dorsal skull profile, little separate parietal crests, narrow braincase, and strong paracoon rib on premolars (Deng, 2001a, b), while the derived characters of *C. anderssoni* include the high position of orbit, absence of supraorbital tubercle, well-developed postorbital process, flat dorsal skull profile, broadly separate parietal crests, rounded braincase, and weak or absent paracoon rib on premolars (Ringström, 1924). *Hystrix*, *Ancylotherium* and *Metacervulus* appeared in the Yangjiashan Fauna. In conclusion, the Yangjiashan Fauna may be appreciably earlier than the Baode Fauna.

4.4 Shilidun Fauna

The Shilidun Fauna comes from the Hewangjia Formation, and its fossils include *Hystrix gansuensis*, *Promephitis* sp., *Chasmaporthetes* sp., *Hyaenictitherium wongii*, *Hipparion* sp., *Shansirhinus ringstomi*, *Cervivitus novorossiae*, *Palaeotragus* sp., *Sinotragus* sp., and *Gazella* sp.

*Chasmaporthetes* sp. and *Shansirhinus ringstomi* newly appeared in the Shilidun Fauna, while the extremely dominant *Chilotherium* in the Late Miocene *Hipparion* fauna disappeared in this fauna. Other members of the Late Miocene *Hipparion* fauna, such as *Adercota*, *Ictitherium* and *Chleuatochoerus* are absent in the Shilidun Fauna. *Chasmaporthetes* has a widespread distribution in the world, and its fossils were discovered from Europe, Asia, Africa, and North America; it first appeared in the Early Pliocene, corresponding to the Ruscinian Age of Europe. In China, *Chasmaporthetes* was discovered from Yushu and Shouyang in Shanxi, Nihewan in Hebei, and Mianchi in Henan (Qiu, 1987). In the Yushu Basin, *Chasmaporthetes* appeared first in the Gaozhuang Fauna with a paleomagnetic age of 5.2-3.4 Ma, when *Chilotherium* had disappeared (Qiu, 1987). The Gaozhuang Fauna should be correlated to MN14-15 of the European mammal ages (Qiu and Qiu, 1995). Kretzoi (1942) established a new genus *Shansirhinus* on the basis of *Rhinoceros brancoii* described by Schlosser (1903) as the type species, and renamed *Rhinoceros* aff. *R. brancoi* described by Ringström (1927) as *S. ringstomi*. *S. brancoi* does not have exact locality and horizon. *S. ringstomi* is collected from Huangshigou in the Nihe district of the Yushu Basin. Qiu et al. (1987a) indicated that the mammal fossils in the Nihe district came mainly from the Gaozhuang Formation, so the age of *S. ringstomi* should be Early Pliocene. Some common species of the Late Miocene *Hipparion* fauna, such as *Hystrix gansuensis*, *Cervivitus novorossiae*, and *Sinotragus* sp. still survived in the Shilidun Fauna, while the derived taxa in the Gaozhuang Fauna, such as *Ursus*, *Nectereutes*, *Canis*, *Hipparion houfenense*, and *Sus* have not been found in the Shilidun Fauna. As a result, the age of the Shilidun Fauna may be early Early Pliocene, approximately corresponding to MN14.

5 Early Pleistocene *Equus* fauna

The Early Pleistocene Dongshan Formation is composed of lacustrine siltstones, but strata corresponding to the Lower Member of the Dongshan Formation in the east side of this basin is loess deposits, i.e., the Wucheng Loess (Fig. 2). The Early Pleistocene *Equus* fauna comes from the Wucheng Loess at Longdan in Dongxiang County, and its fossils include *Aepycerosciurus orientalis*, *Marmota* sp., *Mimomys* cf. *gansunicus*, *Bahomys* sp., *Sericolagus brachypus*, *Macaca anderssoni*, *Paradolichopithecus* sp., *Vulpes chikushanensis*, *Canis* sp., *Meles* sp., *Chasmaporthetes progressus*, *Pachycrocuta licenti*, *Crocuta honanensis*, *Homotherium cretanides*, *Megantereon nihowanense*, *Sivapanthera* sp., *Panthera*

The existence of true horse and the absence of typical Middle Pleistocene forms, like Pachycrocuta sinensis, Sinomegacerus, Bos and Bubalus, immediately put the Longdan fauna in the Early Pleistocene. The Longdan Fauna is slightly older than that of the Nihewan Fauna (Teilhard and Piveteau, 1930) based on the following observations. Although congeneric, the evolutionary levels may be different. Meles sp., Sivapantthera sp. and Gazella cf. blacki of the Longdan fauna are certainly more primitive than their counterparts of the Nihewan fauna. Some primitive forms appeared in the Longdan fauna, but are absent in the Nihewan fauna, like Panthera palaeosinensis, Leptobos brevicornis and Nipponicervus sp. In Nihewan no Panthera and Leptobos were found, and Cervus (Rusa) elegans may be a more advanced species of Nipponicervus. On the other hand, a large number of more advanced forms, especially the cervids, appeared in the Nihewan Fauna, like Axis shansi, Elaphurus bifurcatus, Eucladoceros boulei, Bison palaeosinensis, Paleoloxodon namadicus etc. The extremely large horse, Equus sp. from Longdan, may be a horse species appeared earlier in age than E. sammensis from Nihewan. Similar case can be seen in Europe, where the earliest horse, E. livenzovensis, is also larger than the typical Villafranchian horse, E. stenonis.

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