中国晚新近纪哺乳动物群落与东亚环境变化[1)]

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摘要：根据已有的中国晚新近纪哺乳动物化石记录，综合新近研究成果，初步探讨中国晚新近纪哺乳动物群落演变进程及其对于气候与环境变化的响应。结果表明，自中中新世晚期至晚中新世（约13 Ma至7~8 Ma），中国北方哺乳动物群落组成上没有明显的分异；而在其后的晚中新世晚期发生了较为明显的区域性分化，分化为东部地区以适应潮湿的较为封闭的动物群落与西部地区适应干旱的开阔环境的群落，这种分异可能与东亚夏季风的加强密切相关；青藏高原及其周边地区化石类群的扩散与交流资料也表明由青藏高原隆升而形成的地理阻隔也可能发生在该时期；上新世哺乳动物群落演化表现出对于持续的干旱化气候背景的适应，而晚上新世某些类群的分异与主导地位的确立与该时期气候环境背景的剧烈震荡相一致。由于化石资料的不完整，时段分布的不均一，以及地理分布区域的局限，全面认识中国晚新近纪哺乳动物群落组成以及与环境变化的关系尚有很长的一段历程。

关键词：中国，晚新近纪，群落组成，环境变化

中图法分类号：Q915.873 **文献标识码**：A **文章编号**：1000-3118(2006)02-0133-10

CHINESE LATE NEOGENE LAND MAMMAL COMMUNITY AND THE ENVIRONMENTAL CHANGES OF EAST ASIA

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Abstract Based on the present available fossil mammal data, this paper tries to synthesize the most updated publications on the Chinese late Neogene, and analyze the evolutionary process of fossil mammal communities and their response to climatic and environmental changes. Preliminary results show that fossil mammal communities in North China are rather stable and uniform from the end of Middle Miocene till the latest Miocene (ca. 13 Ma to 7~8 Ma). The differentiation of a humid and closed fauna in the east, a dry and open fauna in the west during the latest Miocene might be closely related with intensification of the East Asian summer monsoon. Fossil mammal dispersal evidences from Tibet and adjacent areas suggest the formation of a geologic barrier due to uplift of the Tibet Plateau that might also be the cause of intensification of the East Asian summer monsoon. The Pliocene faunas from North China show strong adaptation to open and dry environments. The diversification and dominance of some lineages, such as siphneids and ochotonids, may well be explained by the climatic vibration during the late Pliocene. Due to the incompleteness, unevenness, and poor geo-

1)国家重点基础研究发展规划项目（编号：G2000077707）、国家自然科学基金项目（编号：40272009）和科技部国际合作项目（编号：2002CB714002）资助。

收稿日期：2006-01-04

graphic coverage of mammal fossils, more work is wanting for achievement of this important and interesting issue discussed herein.
Key words Chinese late Neogene, mammal community, environmental changes

1 Introduction

Increasing evidences show that Chinese late Neogene (Late Miocene and Pliocene) witnessed dramatically environmental changes. Though still in dispute with the process and pattern, the uplift of the Tibetan Plateau should be the most prominent physical change that shaped the present topographic frame of East Asia. It is now generally accepted that uplift of the Tibetan Plateau may be responsible for both the late Cenozoic cooling and significant strengthening of the Asian monsoon system (Kutzbach et al., 1993). Geological data and computer modeling were used to support the hypothesis of intensified uplift of the Tibetan Plateau around 8 Ma causing the enhanced aridity in the Asian interior and onset of the Indian and east Asian monsoons (An et al., 2001). Though the initial time of the Asian monsoon system is challenged by new evidences from Miocene loess (Guo et al., 2002), pollen data and other paleobotanical evidences (Wang et al., 2005; Sun and Wang, 2005), there are many evidences from the Loess Plateau showing the changing process of summer and winter monsoon intensification during the late Neogene (Ding et al., 1999; Qiang et al., 2001; Vandenberghe et al., 2004).

Ecologically, there are some evidences showing the expansion of C4 grass in northern Pakistan and Nepal around 7 ~ 8 Ma (Cerling et al., 1997). In China, there has no evidence yet showing the simultaneous change occurred at this time. Ding and Yang (2000) suggested that C4 plants expanded at ~ 4 Ma on the Loess Plateau in a recent isotopic study of paleosol carbonates in a late Cenozoic red-clay and loess sequence at Lingtai. The most recent data from the Linxia Basin suggested that C4 grasses were either absent or insignificant in the Linxia Basin prior to ca. 2 ~ 3 Ma and only became a significant component of local ecosystems in the Quaternary (Wang and Deng, 2005), while the earliest definitive C4 signal in fossil enamel from China is from Yushe which is located further east of the Linxia Basin.

The evolutionary process of land mammals has been intuitively thought to respond in different scales and patterns to environmental changes. The increasing mammal fossils excavated in the last decades under a more precise chronological frame provide the possibility to discuss the interaction of environmental changes and evolutionary process of terrestrial mammals. Fortelius and Zhang (in press) has tried to analyze the fossil mammal endemism during the late Neogene and discussed the relationships with possible climatic changes. In this paper, the author will try to synthesize the most updated data, and qualitatively analyze the community structures of Chinese late Neogene, and discuss their possible interaction with environmental changes.

2 Method

The biochronology of Chinese late Neogene has long been one of the main subjects for Chinese paleontologists. The Neogene local faunal sequence was set up by Li et al. (1984), and later on by Qiu (1990), Tong et al. (1995). However, most of local faunas of the late Neogene were relatively isolated, and not well calibrated stratigraphically (Tedford, 1995). Hence, some continuous sections or sedimentary basins were chosen as targets for further biostratigraphic study. For example, the Sino-US cooperate study on the Yushe Basin. The restudy at the Lantian area by the Sino-Fennic cooperation team shows that there developed continuous sections ranging from the early Late Miocene to Pliocene and up to the loess along the Bahe river (Zhang et al., 2002; Kaakinen, 2005). The sections near Leijiahe village of Lingtai, about 300 km north of Lantian, produced very rich fossil mammals, especially small mammals with well calibrated strata and densely sampled levels, covering the latest Miocene to early Pleistocene (ca.

7 ~ 2Ma). The Hezheng sections with rich fossils also improve greatly the biochronologic correlation of North China. All these sequences with abundant mammal fossils provide much finer biostratigraphic framework of Chinese late Neogene.

For understanding of the ecological background of a certain fauna, analogy to the present fauna in a certain area is one of the most frequently applied measures in the discussion of the late Neogene faunas which have close relationships with the nowadays faunas at the familiar or generic level. Some lineages having specified ecomorphology are also used to infer their ecological background.

3 Land mammal community

3.1 Late Middle Miocene

The geographic distribution of fossil mammal localities of late Middle Miocene (Tunggurian) covers a great variety of Chinese territory from the most western locality, Xinjiang, to the eastern Xin'an (Hebei Province), from the northern Tunggur (Nei Mongol) to the southern Fangxian (Hubei Province), and further the southern most Kaiyuan (Yunnan Province).

Small mammals from Tunggur are very diversified, there totally recorded 39 species of 27 genera (Qiu, 1996). By the community structure, and the dominance of cricetids, zapodids, and ochotonids, Qiu (1996) suggested a generally temperate steppic or at least open environment for the fauna. Large mammals consist of both low-crowned browsers, such as *Stephanocemas*, *Chalicotherium*, *Anchitherium*, *Platybelodon*, *Serridentinus* and high-crowned forms, such as *Turcoceros* and rhinos (Wang et al., 2003). The mixture pattern of large mammals fits the pollen data that show the existence of a large number of herbaceous pollen taxa such as Chenopodiaceae (17.5% ~ 26.8%) and *Artemisia* (18.4% ~ 23.9%), inferring steppe or forest steppe vegetation (Wang, 1990).

The similar community structure of the Tunggur fauna has also been recorded in the Xianshuihe fauna (Gansu Province), and a fauna from the Kekemaideng Fm., Xinjiang Province (Ye et al., 2000). To the south, a large mammal fauna from Fangxian, though only four taxa produced (Yan, 1979), includes three typical species of the Tunggur fauna. High crowned elasmothere *Tesselodon*, *Turcocerus*, and the large sized pig *Listriodon* suggest a relatively open environment. Contrary to these faunas from North China (north of the Yangtze River), the Xiaolongtan fauna of Kaiyuan, Yunnan Province produced typical forest elements, such as the primates *Sivapithecus*, *Tapirus* etc. The ecological pattern at the end of Middle Miocene suggested by fossil mammal records is similar with the present scheme, however, with less aridification in North China.

3.2 Late Miocene

Present data show that Late Miocene mammals reached their maximum diversity at the generic level during the late Neogene (Zhang et al., in press). However, mammal fossil localities of the early Late Miocene (Vallesian equivalent) are relatively rare from China. Till now, only few localities have paleomagnetic dating and reliable mammalian biochronologic calibration, such as the fauna from the lower part of the Bahe Formation, which produced *Progonomys* (Zhang et al., 2002; Qiu et al., 2004a), the most derived *Protolactaga* (Li and Zheng, 2005), *Myocricetodon* and *Abudhabia* (Qiu et al., 2004b) etc. Fauna comparison and paleomagnetic dating of localities from the lower part of the Bahe Formation strongly suggest a Vallesian equivalent age (Zhang and Liu, 2005; Kaakinen, 2005). Except the widely distributed murine *Progonomys*, small mammals are mainly consisted of Cricetidae, Dipodidae, Gerbillidae and Ochotonidae. The diversity of Dipodidae, the presence of Gerbillidae and Ochotonidae, generally indicate a steppe or semi-desert environment, or at least a dry and open environment, similar to the southern part of Mongolia-Xinjiang today (Qiu et al., 2003). A large bovid, *Lantiantragus longirostralis* (Chen and Zhang, 2004), with short premolar rows and square shaped molars, also suggests its adaptation to a dry and open environment.

The Tsaidam fauna, with elements of *Anchitherium* fauna and *Hipparion* (Bohlin, 1937), have long been considered as a representative of the early Late Miocene faunas of China (Qiu and Qiu, 1995, Qiu et al., 1999), however, might be a mixture of Middle Miocene and Late Miocene elements due to surface collecting (Deng and Wang, 2004).

Another fauna, from Amuwusu, is also considered as one of the earliest Late Miocene faunas, which produced more than 28 small mammal species (Qiu and Wang, 1999). Though without systematic study, among the 20 determinable genera 12 are recorded from the Tunggur fauna. New elements replaced the corresponding ecological niches of those Middle Miocene ancestors, i. e. *Ochotona* replaced the ecological niche of *Bellatona* and *Alloptox*; *Prosiphneus* replaced *Plesiodipus*. The similarity and continuity with those of the Tunggur fauna suggest the stability of the environment across the Middle/Late Miocene boundary.

From the early Late Miocene on, fossil mammals from the Bahe Formation show strong continuity in the fauna composition (Zhang et al., 2002) with minor changes at the generic and/or specific level. The medium sized bovid *Shaanxispira*, small sized *Dorcadoryx*, and *Gazella* are dominants of ruminants, while cervids and pigs are rare. Perissodactyls are characterized by the dominant of Equidae and Rhinocerotidae. Small mammals evolved gradually into derived species without fauna composition changes. The stability of environment during the early and middle Late Miocene suggested by the fossil mammal community also fit the stable sedimentological environment. The Bahe Formation displays a series of similar sediment cycles from the base to the top, although there is a slight upwards-fining trend in the sedimentary sequence. Based on the sedimentary succession and facies characteristics, the maturity of paleosols and the fossil content within the Bahe Formation, it is evident that fluvial activity in the paleo-Bahe anastomosing river system persisted in the area, in a relatively constant manner, for a period of several million years (Kaakinen and Lunkka, 2003).

The similar scenario also occurred at the Linxia Basin, Gansu Province where a great number of fossil mammals were collected in recent years (Deng et al., 2004). From the Liushu Formation, there found three successive fossil levels. The lower level was considered to be early Late Miocene by the primitiveness of *Hipparion* species and the occurrence of *Dinocrocuta gigantea*. The middle level was correlated with the Bahe Formation and Fugu lower fossil level by the faunal composition. The Upper level was comparable with that of the typical Baode fauna. However, except the extinction, such as *Dinocrocuta*, and replacement of derived species, there recorded no changes of the faunal community structure for all three stages.

While in the Lantian area, Shaanxi Province, an obvious faunal structure change was recorded at about 7 ~ 8 Ma from an open and dry environment to a relatively closed and humid environment. Some elements, such as *Chleuastochoerus stehlini*, *Cervavitus novorossiae*, *Typhlomys*, which have not been recorded from the Bahe Formation occurred from the bottom of the Lantian Formation. Deer, pigs, and lower crowned gazelles replaced the domination of large bovids in the Bahe Formation. The faunal community differentiation during the latest Miocene was first noticed by Schlosser (1903), and later studied in detail by Kurtén (1952) with the hypsodonty of fossil mammals. The discrepancy of environment changes suggested by fossil mammal community structure can possibly be explained by the intensity of the East Asia summer monsoon.

Before the latest Miocene (ca. 7 ~ 8 Ma), the summer monsoon was probably not strong enough to reach the Loess Plateau, including the Lantian area. After that, the intensification of summer monsoon brought enough precipitation in the eastern part of North China and shaped a different fauna structure from the west. The recent study of tooth enamel carbon and oxygen isotopes shows that there is no expansion of C4 grass in the Linxia Basin prior to 2 ~ 3 Ma, which is explained as the less intensity of the East Asian summer monsoon (Wang and Deng, 2005).

Fossil mammals discovered from the Tibetan Plateau contributed greatly to the understanding of the uplifting of the Plateau. In the north Tibet, a *Hipparion* fauna was found in 1970s (Zheng, 1980), which consists of ten species. The fauna was compared with those of Siwaliks, and considered to be Vallesian equivalent in age. Restudy of the small and primitive *Dinocrocuta* and *Hipparion* approved the biochronology estimation (Zhang, 2005; Qiu et al., 1987). The small sized *Dinocrocuta* was also recorded from Turkey (Ozansoy, 1965; Viranta and Werdelin, 2003). The commonness of small mammals from the lower part of the Bahe Formation with those from Turkey, and further to Africa, also indicates the possible nonexistence of a geographic and or ecologic barrier between the west and east Asia during the Vallesian Stage. It is highly unacceptable by the fauna composition of Biru and the faunal communication that the Tibet Plateau has been remained unchanged since 15 Ma suggested by Spicer et al. (2003). From the southern slope of the Himalayan Mountains, another *Hipparion* fauna was also discovered near Jilong in 1970s (Ji et al., 1980). New paleomagnetic dating shows the age of the Jilong *Hipparion* fauna is about 7.0 Ma (Yue et al., 2004). Recent excavation and small mammal fossil sieving show that this fauna is dominant by ochotonids, high crowned cricetids, *Palaeotragus* and other bovids. Though in a comparable age with the typical Baode fauna, the Jilong fauna is very different in the faunal composition at specific level. The dominance of ochotonids strongly suggests a high elevation background considering of its geographic location. The different faunal composition with those from the west Asia clearly indicates the geographic and or ecologic barrier at that time. This scenario seems to fit the conclusion of Harrison et al. (1992) and An et al. (2001) that the Tibet Plateau should have raised to a critical height prior to 7 ~ 8 Ma.

Miocene fossil localities in the south China are mainly from Yunnan Province, e. g. Lufeng and Yuanmou. Ni and Qiu (2002) analyzed the paleoecology of Yuanmou and Lufeng faunas by the micromammal fossil community, and suggested a typical humid and warm forest dominant environment for both faunas.

3.3 Pliocene

Contrary to the rich fossil mammal localities found from the latest Miocene, there have relatively poor geographical coverage of mammal localities in the early Pliocene.

From the Linxia basin, a fauna from the Hewangjia Formation was considered to be early Pliocene (Deng et al., 2004). The occurrence of *Chasmaportes* and *Shansirhinus ringstromi* was the main biochronologic evidences. Paleomagnetic interpretation of the sections from the Linxia basin by Fang et al. (2003) is obviously not satisfied in the paleontological view, such as the age of the *Hipparion* fauna from the Shangzhuang Formation was interpreted to be Middle Miocene. If the Hewangjia fauna is early Pliocene, there seems to be no change of the faunal composition from those of the late Miocene in this area.

Two localities from Nei Mongol, e. g. Ertemte and Harr Obo produced both rich large and small mammals. The age of Ertemte fauna has been referred to the terminal Miocene by Fahlbusch et al. (1983), Qiu and Qiu (1995), Flynn et al. (1995), Qiu et al. (1999), but argued by Zhang and Zheng (2000) as early Pliocene based on the comparison with small mammals from Lingtai sections. Large mammals from Ertemte fauna have been studied by Schlosser (1924) and not systematically revised till now. Qiu and Qiu (1995) give a faunal list of Ertemte fauna and recognized some derived large mammals, such as *Meles*, *Martes*, *Procapreolus* etc. However, the main elements of this fauna consisting of *Hipparion*, *Sinohippus*, *Chilotherium*, *Honanotherium*, *Palaeotragus*, *Icthitherium* etc. are very close to those from the typical Baode faunas. Harr Obo produced a very similar micromammal fauna with some slightly derived species (Qiu, 1987, Storch, 1987). *Rhagapodemus* sp., similar to the oldest European species that made their first appearance during the early Ruscinian, also suggests that the Harr Obo fauna is slightly younger than the Ertemte fauna (Storch, 1987). Among the small mammals, murines are the most diversified group, there recorded six genera from these two localities, and other genera such as primitive species *Chardinomys*, *Huaxiamys* from Lingtai (Zheng and Zhang, 2001).

The only early Pliocene fauna with reliable paleomagnetic dating is from the Nanzhuanggou and/or Culiugou members (Flynn et al., 1997). Though the full descriptions of fossil mammals have not been published, an obviously community change across the Miocene/Pliocene boundary can be recognized by the distinction of the Late Miocene genera, *Adcrocuta*, *Hyaenictitherium*, *Ictitherium*, *Chleuastochoerus*, *Honanotherium*, *Sinohippus* etc. New immigrates, such as camelids, canids, and arvicolids boomed and diversified. The possibly environmental change occurred at the Miocene/Pliocene boundary can be detected by the general faunal community structures, but the detailed process is still in its infancy. The poor geographic coverage of fossil localities during this time interval hinders the further exploration of the ecological divergence.

For the paucity of early Pliocene large mammal records, faunal community changes during the early/middle Pliocene have not been fully shown. From the Lingtai sections, there recorded no faunal community changes during this time interval. The anagenetic evolutionary process of small mammals shows increase of crown height, lophodonty, and root number on molars etc., suggesting a steady aridification tendency.

Fossil localities from Nei Mongol also witnessed the same tendency. Fifty species of 41 genera of small mammals discovered from Bilike, Nei Mongol constitutes the most diversified and abundant micromammal fauna in the Pliocene. The Bilike fauna shows a strong similarity with the Ertemte fauna and both have all the families and half of the genera in common, even 21 species are considered conspecific (Qiu and Storch, 2000). The predominance of *Aratomys*, cricetine hamsters, *Ochotona* and *Prosiphneus* points to the increase of aridity.

Compared with the diversification of murines during the interval of the Biozone Ⅲ and Ⅳ of the Lingtai section, the abundance and diversity of ochotonids and siphneids in the Biozone Ⅴ should be the major character of the faunal composition change. There recorded six species of ochotonids and 8 species of siphneids (Erbajeva and Zheng, 2005; Zheng and Zhang, 2001). Dipodids and gerbilids also boomed during this time. The Biozone Ⅴ was interpreted to be 3.6 ~ 2.6 Ma by the preliminary paleomagnetic data and biochronology (Zheng and Zhang, 2001). During this time interval, there recorded much more fossil mammal localities, such as Mazegou in the Yushe basin, Jingle, Daodi etc. from north China. The Mazegou Formation produced the largest large mammal collection of the late Pliocene. Tedford et al. (1991) listed the fossils at the generic level, which shows strongly diversification of bovids, such as *Sinoryx*, *Megalovis*, *Antilospira*, and *Lyrocerus* etc. Large deer, such as *Axis*, *Dama*, *Rusa* are also recorded. However, there is only one genus, *Sus* of the suids recorded. Canids replaced the dominance of hyaenids in the previous time intervals. To the end of Pliocene (Pliocene/Pleistocene boundary at 2.6 Ma), at the Mazegou-Haiyan contact, nearly a quarter of large mammal genera, and 84% of rodent species of the Mazegou fauna failed to persist into the early Pleistocene (Tedford et al., 1991). Small mammals from Lingtai show more severe faunal changes. Contrary to the abundance and diversification in the Late Pliocene, rootless siphneids, arvicolids, ochotonids dominate the fauna from the lower part of the Loess with a much less diversification. The faunal change fits well with the aridification and strong winter monsoon indicated by the study of the loess (Liu et al., 1985).

4 Discussion

Base on the fossil mammal data from China available, neglecting the incompleteness of fossil records, the faunal community structures during the late Neogene have relatively been in a stable situation without severely faunal changes at higher taxonomic levels.

From the end of Middle Miocene to the latest Miocene, prior to 7 ~ 8 Ma, there recorded no visible ecological differentiation for the faunas from North China. The open grassland with a certain amount of forest might occupy the large area north of the Yangtze River. The uniformity of the ecological background in North China seems to be not favorable for the strong seasonality and onset the East Asian monsoon. The faunal communication during the early Late Miocene also suggest the possible nonexistence of a geographic and or ecological barrier between the east and west Asia, also support the above evidence.

In recent years, flourishing papers on the Red Clay have been published. Different proxies, such as susceptibility, grain size, carbon and oxygen isotope and others, are applied to indicate the climatic variations during the late Neogene (Sun et al., 1998; Ding et al., 1998, 1999; An et al., 2001; Lu et al., 2001; Qiang et al., 2001; Vandenberghe et al., 2004; Wang and Deng, 2005; Guo et al. 2002). Though still in dispute with interpretation of different proxies, more evidences shows the onset of the East Asian monsoon during the late Miocene, which is possibly caused by the uplift of the Tibet Plateau.

Ecological differentiation of the faunas from North China at the end of Late Miocene (ca. 7 ~ 8 Ma) into the relatively humid and closed pattern in the eastern south area and the dry open pattern in the western north area of North China implies the intensification of summer monsoon. This interpretation was also shown by the study of hypsodonty of herbivores (Fortelius et al., 2002) and endemism (Fortelius and Zhang, in press).

The scarcity of fossil records from the early and middle Pliocene hinders the detailed exploration of the ecological differentiation of the faunas. Rich fossils from the late Pliocene with abundant and diversified taxa adapted to the steppe and grassland, such as ochotonids, siphneids, dipodids, gerbillids, strongly suggest the environmental deterioration and vibration, which were also indicated by the independent geologic proxies. However, the cause of this climatic and environmental change is in dispute, whether it was caused by the rapid uplift of the Tibet Plateau or the development of the North Hemisphere glaciation (An et al., 2001).

5 The Future

Because of the incompleteness, unevenness, and poor geographic coverage of fossil mammal records, the full understanding of the evolutionary process of mammalian communities is still in its infancy stage. More detailed work with the biochronology of isolated localities and continuous sections with rich fossils and reliable chronological calibration in different geographic areas will greatly improve the present understanding. Late Neogene fossil localities from south China should be one of the most urgent targets in the future field survey. Early Pliocene localities from North China are also critical.

Meanwhile, the systematic study of endemic lineages, and their ecomorphologic adaptation to the environmental variations together with the developing of some proxies will possibly keep the pace with other geologic measures under a similar chronological frame.

Acknowledgements The author thanks cordially all his colleagues involved in the painful and fruitful projects in recent years for sharing their knowledge and stimulating discussions.

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