

中国晚中新世陆相哺乳动物群序列： 陕西蓝田的新证据¹⁾

张兆群¹ A. W. Gentry² A. Kaakinen³ 刘丽萍^{1,3} J. P. Lunkka⁴
邱铸鼎¹ S. Sen⁵ R. Scott⁶ L. Werdelin⁷ 郑绍华¹ 傅铭楷³

(1 中国科学院古脊椎动物与古人类研究所 北京 100044)

(2 英国自然历史博物馆 伦敦 SW7 5BD)

(3 芬兰赫尔辛基大学地质系 赫尔辛基 P. O. Box 64, FIN - 00014)

(4 芬兰图尔库大学地质系 图尔库 FIN - 20014)

(5 法国自然历史博物馆 巴黎 75005)

(6 美国德克萨斯大学人类学系 奥斯汀 78712 - 1086)

(7 瑞典自然历史博物馆 斯德哥尔摩 S - 104 05)

自 20 世纪 60 年代,陕西蓝田地区就以连续的晚新生代地层及丰富的哺乳动物化石而成为研究中国晚新生代哺乳动物与地层划分对比的经典地区之一。李传夔等(1984)根据灞河组发现的哺乳动物化石建立了灞河期,并与欧洲的 Vallesian 期对比。邱占祥等(1990,1995)认为化石证据不充分,而将其与保德期合并。近年来,黄土高原三趾马红粘土大量的年代学资料表明,红粘土沉积最早可能开始于约 8Ma 前。因此,狭义的保德期可能只代表了晚中新世晚期,晚中新世哺乳动物分期的再划分问题又重新被提出。

自 1997 年以来,我们课题组在蓝田地区共发现 52 个化石地点,其中的 26 个含有哺乳动物化石,大哺乳动物化石标本共计 1666 件。经过详细野外地层测量,绘制了综合地层剖面,并将主要含哺乳动物化石的地点对比标定到综合地层剖面上。经过对各门类化石的初步研究,以及对已有化石材料的初步修订,到目前为止,陕西蓝田灞河组共计发现哺乳动物化石 45 种,蓝田组 20 种。

新的化石证据表明,灞河组发现的哺乳动物化石组合完全不同于典型意义上的保德三趾马动物群。大哺乳动物化石以灞河三趾马与贾氏三趾马为代表,牛科化石组合在种级甚至属级上有明显的区别。大量的陕西转角羚羊,小型的 *Protoryx*、*Dorcadoryx* 以及 *Gazella* cf. *G. lyderkeri* 等,与三趾马红土中常见的 *Umiatherium*-*Plesiaddax*, *Sinotragus*-*Protoryx*, *Gazella gaudryi*-*Gazella dorcadoides* 等形成了明显的对比。食肉类化石较少,但灞河组中巨鬣狗化石与保德期 *Adcrocuta*-*Hyaenictitherium*-*Ictitherium* 组合仍有明显的差异。另外,灞河组中的鹿科化石无论从种类还是数量上均明显较少。小哺乳动物化石面貌更有别于我国已知晚中新世组合,如内蒙古二登图、甘肃灵台等。已发现的 19 个种中,除部分为新属外,还有 3 个属(*Abudhabia*、*Myocricetodon*、*Progonomys*)是在我国的首次发现。蓝田组底部(红粘土之下)发现的与保德动物群相当的大量化石材料表明,动物群组合的转换时期发

1) 国家重点基础研究发展规划项目(编号:G2000077707)资助。

收稿日期:2002 - 01 - 21

生在灞河组与蓝田组界线附近或稍早。根据孙东怀等(1997)的古地磁解释,蓝田组红粘土沉积开始于约 6.8Ma 前,推测此转换过程可能稍早于 7Ma。基于以上新的化石材料与详细的地层学工作,灞河期将有可能重新被启用,而保德期虽然还没有详细的生物地层学工作,但其时代应当晚于灞河期,只代表晚中新世晚期。

灞河期与保德期之间发生的动物群生态类型的转变显示出明显的区域性特征,与欧洲、西亚等地区不同,晚中新世气候环境与生态类型的变化并不是从相对湿润的森林环境向干热的草原环境的转变,而是从干热的草原向相对湿润的森林草原转变,推测有可能与青藏高原的隆升引起的东亚季风气候体系的改变,尤其是夏季风加强有关。

另外,蓝田地区以及黄土高原红粘土沉积研究资料还表明,沉积类型的变化(河湖相沉积向风成土状堆积转变)既受全球变化的影响,又受到地方环境的控制。

关键词 陕西蓝田,晚中新世,哺乳动物群序列,环境变化

中图法分类号 Q915.873,P534.621

LAND MAMMAL FAUNAL SEQUENCE OF THE LATE MIOCENE OF CHINA: NEW EVIDENCE FROM LANTIAN, SHAANXI PROVINCE

ZHANG Zhao-Qun¹ GENTRY Alan W.² KAAKINEN Anu³ LIU Li-Ping^{1,3} LUNKKA Juha Pekka⁴ QIU Zhu-Ding¹ SEN Sevet⁵ SCOTT Robert S.⁶ WERDELIN Lars⁷
ZHENG Shao-Hua¹ FORTELIUS Mikael³

(1 *Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences Beijing 100044*)

(2 *c/o Department of Palaeontology, the Natural History Museum London SW7 5BD*)

(3 *Department of Geology, University of Helsinki Helsinki P.O. Box 64, FIN-00014*)

(4 *Department of Geology, University of Turku Turku FIN-20014*)

(5 *Laboratoire de Paléontologie du Muséum Paris UMR 8569 du CNRS, 8 rue Buffon, 75005*)

(6 *Department of Anthropology, the University of Texas Austin TX USA 78712-1086*)

(7 *Swedish Museum of Natural History Stockholm Box 50007, S-104 05*)

Abstract Newly discovered fossil taxa and preliminary revision of the old collection from the Bahe and Lantian formations allow a re-interpretation of the mammalian faunal sequence of the Chinese Late Miocene. The distribution of fossil taxa in the strata shows a major turnover event within the late Miocene, at a time slightly preceding the sedimentological change represented by the boundary between the Bahe and Lantian Formations (ca. 7Ma). The mammal fauna postdating the change shows a strong resemblance to the classic Baodean mammal faunas of North China. Based on this turnover event a resurrection of the Bahean Land Mammal Age, predating the Baodean LMA within the late Miocene, would be possible. The Bahean/Baodean turnover event was ecological as well as taxonomic and suggests significant climatic change at this time, possibly driven by onset or intensification of the East Asian summer monsoon circulation system.

Key words China, Late Miocene, Faunal sequence, Turnover, Land Mammal Age, Environmental change

1 Introduction

The late Miocene sediments in the Lantian area, Shaanxi Province, China have produced a substantial collection of mammalian fossils (Liu et al. 1960, 1978; Zhang et al., 1978). In 1984, Li et al. erected a Land Mammal Age (LMA), the Bahean, represented by fossils from the Bahe Formation (mainly from its upper part), and suggested a preliminary correlation with the European Vallesian stage. This interpretation was maintained in the widely cited summary by Qiu (1990).

Soon afterwards, Qiu and Qiu (1990, 1995) combined the Bahean with the Baodean (s. s.) into a more inclusive Baodean (s. l.). This extended concept of the Baodean thus represented the entire Late Miocene of China, reflecting the belief that the fossil evidence for a finer subdivision was insufficient.

The "Baode Red Clay" has never been geologically and biostratigraphically restudied after Zdansky's work in 1924. Recent paleomagnetic work on the "Fugu Red Clay" and other sections from the loess plateau, from which the typical Baode *Hipparion* fauna discovered, reveals that deposition of the Red Clay most probably begun at about 8 Ma (Xue et al., 1995; Sun et al., 1998; Ding et al., 1998; Qiang et al., 2001). Therefore, the Baodean Land Mammal Age is evidently restricted to the later part of the late Miocene in its type area. This finding reopens the question of biochronological subdivisions of the Chinese late Miocene.

Liu et al. (1978) recognized three phases of faunal and environmental development in the late Miocene of the Lantian sequence. According to them, the first phase was characterized by a closed, forested habitat, the second phase was more open, and the last phase was again more closed. This interpretation differs substantially from the conventional view of late Miocene habitat change as a global trend towards increasingly open, arid, and seasonal environments (e. g., Janis, 1993). In view of the subsequent development in palaeoclimatological understanding it now seems timely to reconsider the environmental implications of the mammal faunas from Lantian, which represent a unique geographic and temporal datum within the late Miocene of Eastern Asia.

Since 1997, our group has carried out five field seasons in the Lantian area. Totally 52 new fossil localities (among them 26 with mammal materials) were found and 1666 large mammal specimens discovered by excavation and prospecting. Preliminary analysis of small mammals from the Bahe Formation suggests that the Bahe Formation predates the type Baodean, being roughly correlative with the European MN 10 ~ 11 zonation (Qiu et al., to be published¹⁾).

Here we present briefly the new results, with comments mainly on large mammal fossils and analysis on fauna changes along the section. Our new fossil localities are calibrated into a synthetic profile, with the main old localities of the 1960's included.

2 Geologic setting and fossil localities

The Lantian region is located north of the Qinling Mountains, in the southeastern part of Weihe Graben. Weihe Graben was formed in the early Tertiary and the deposits in the graben represent sediments that were laid down since the Eocene (Zhang et al., 1978).

The sections studied in the present field project are exposed along the eroded cliffs of the Bahe River valley (Fig. 1).

The individual sections were logged in detail and correlated into a single, composite log covering the whole sequence. The localities of the section and their vertical facies changes are summarized in Fig. 2.

The Bahe Formation is a ca. 300m thick fluvial sequence. The fluvial strata accumulated through time by channel cutting, filling and significant vertical floodplain aggradation. The lower part of the Bahe Formation comprises thick and prevalent conglomerates that alternate with cross-stratified and massive sand and mudstone units. These elements represent channel fills, longitudinal and transverse bars and levee sands. The mudstone facies represents floodplain deposits that include several moderately developed paleosol horizons. In the upper part of the formation the thickness of individual sandstone bodies decreases and the channel-related facies becomes laterally restricted. The sand units in this upper part represent mainly crevasse channels and splays. In general, the mudstone deposits dominate over the sandstone and gravel facies throughout the sequence. These

1) Qiu Z. D., Zheng S. H., Sen S., Zhang Z. Q. Late Miocene micromammals from the Bahe Formation, Lantian, China. *Deinsea* (Annual of the Natural History Museum Rotterdam), to be published.

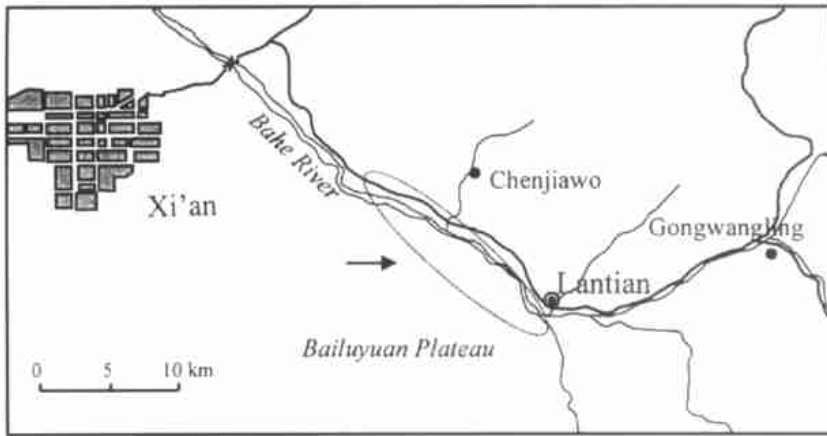


Fig. 1 Sketch map of the study area. Spotted circle shows the main fossil locality area

overbank sediments are laterally extensive and their thickness ranges up to 20m.

The Lantian Formation overlying the Bahe Formation is ca. 50m thick in the study area. It consists mainly of red brown mudstone and abundant carbonate-rich horizons that range in thickness from a decimeter up to two meters. Individual scattered carbonate nodules are also present throughout the formation. The boundary between the Red Clay and the underlying fluvial sediments is often gradational, with sandy lenses and horizons still present in the lower part of the Red Clay. Liu et al. (1960) and Zhang et al. (1978) included the transitional zone in their concept of the Lantian Formation, and we continue this formal usage here, but emphasize the gradational nature of the change in lithology. The origin of the Red Clay is still controversial (e. g. Guo et al. 2001), but several studies (e. g. Liu et al., 1988; Ding et al., 1998; Sun et al., 1998; Lu et al., 2001) have suggested that it is aeolian in origin.

The sequence studied contains vertebrate fossils but is not uniformly fossiliferous. The fossil assemblages are greatly restricted both horizontally and vertically. The vertebrate remains are primarily found in paleosol horizons formed in overbank mudstones (e. g., Locs. 6 and 33) and crevasse splay sands (e. g., Locs. 31 and 19). Fossil concentrations also occur in distal fines of a flood basin (e. g., Locs. 12, 34 and 35) but fossil bones occur only occasionally in large channel lags and fills.

Locality 30 was found in a slumped block from pedogenically altered siltstone at the top of an upward fining unit. However, the similar sediment succession was found from a higher level of the exposure and a tentative correlation of the slumped block into the sequence was possible.

Locality 42 is situated in the Lantian Formation, in the transitional zone between fluvial and aeolian deposition. Locality 44 is situated in a tectonically displaced block but the sediments where the fossils were found indicate that the locality can be placed into the lower Lantian Formation. Locality 49 was found in a small gully between cultivated areas, where only a narrow strip of section is exposed. Therefore, the correlation of this exposure and locality, beyond the fact that it is clearly in the Bahe Fm, is uncertain and the tentative correlation of the locality 49 here is based on its fossil content.

3 Fossil mammals of the Bahe and Lantian formations

The mammal localities range from about 55m above the base of the section to Loc. 42 at about 280m above the base. The distribution is clumped, with most localities concentrated near the 150 and 200m levels (Fig. 2). The large fossil mammals known from the Bahe and Lantian formations currently comprise taxa of the orders Carnivora, Artiodactyla, Perissodactyla, and Proboscidea (Ta-

ble 1).

3.1 Large mammals

Hyaenidae Three species of hyaenids were collected from Loc. 42: the common, dog-like forms *Hyaenictitherium wongi*, *Ictitherium viverrinum*, and the large-sized *Adcrocuta eximia*. All three are represented by well-preserved skulls and mandibles. The presence of *Adcrocuta* indicates a maximum age of MN 10 for Loc. 42.

Percrocutidae The very large *Dinocrocuta gigantea* was collected from our Loc. 6. This taxon was described by Liu et al. (1978) from old locality S2 as *Crocuta macrodonta*. This taxon has also been recorded from Fugu (Zhang and Xue, 1996), Hezheng (Qiu et al., 1988) and other localities.

The remaining carnivore material from Lantian is mostly very incomplete and in need of detailed study. A posterior part of a skull from Loc. 6 can be tentatively identified as a juvenile individual of cf. *Hyaenictitherium hyaenoides*, a large, dog-like form. A set of associated bones of the arm and hand from Loc. 6 probably represents a medium sized felid.

Suidae Only two suid species have been recovered from Lantian, both represented by a very small number of specimens. One is the endemic Chinese suine *Chleuastochoerus stehlini*, the other is a larger suine referred by Liu et al. (1978) to a new species of *Dicoryphochoerus*. From the published figures and measurements, the latter is attributable without question to the genus *Microstonyx*. The species-level taxonomy of *Microstonyx* is currently too confused to make a species attribution meaningful. The Lantian form is smallish, with moderately enlarged posterior molars. It is much too small to be attributed to the South Asian genus *Hippopotamodon* (= "*Dicoryphochoerus*"). Suids are known only from localities 42 and 44, both in the base of the Lantian Formation.

Cervidae *Cervavitus novorossiae* is common in the localities of the Lantian Fm, and material referable to ? *Procapreolus* is also present. From the Bahe Formation only *Metacervulus* sp. is known, represented by a few specimens from Loc. 33. The dental wear morphology (Fortelius and Solounias, 2000) of *C. novorossiae* is very rounded, suggesting that the species included a significant proportion of abrasive food (most probably grass) in its diet. *C. novorossiae* is found in eastern European Turonian localities, and a related form in Kazakhstan (Tleuberdina, 1982). Presumably many later cervine deer derive from an ancestry near *C. novorossiae*, but the paths of descent have yet to be worked out.

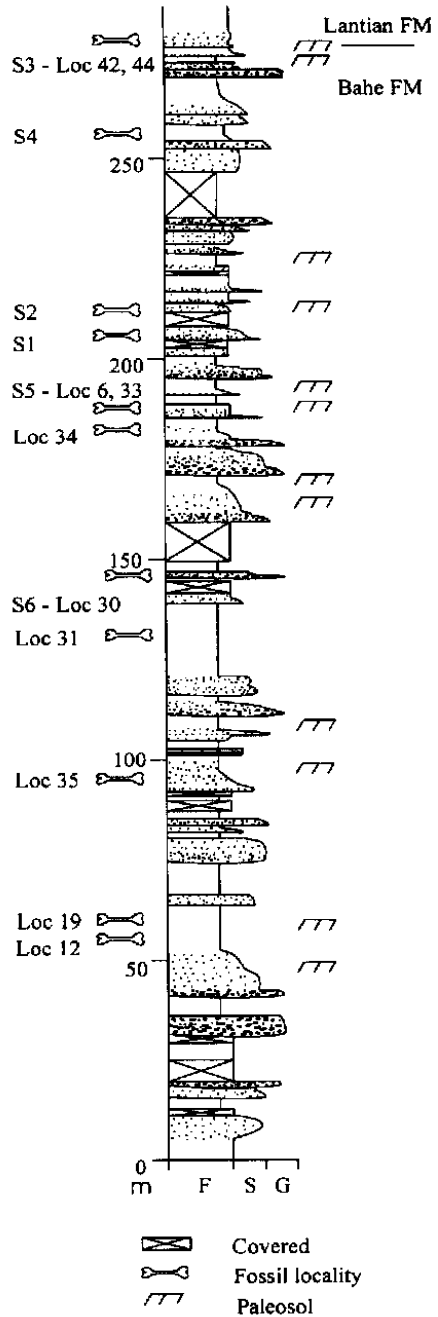


Fig. 2 Composite log and fossil localities

Fig. 2 Composite log and fossil localities

Table 1 Fossil mammal taxa and their localities from Bahe and Lantian formations

| Taxa | Bahe Fm. | | | | | | | | | | | | | | | | Lantian Fm. | | | |
|---|----------|-----|-----|-----|-----|-----|-----|----|-----|-----|----|----|----|----|----|-----|-------------|-----|-----|---------|
| | L12 | L19 | L35 | L38 | L13 | L31 | L30 | S6 | L34 | L33 | L6 | S5 | S1 | S2 | S4 | L42 | S3 | L44 | S10 | |
| Viverridae gen. et sp. indet. | | | | | | | | | | | | | | | | | | | | x |
| cf. <i>Metailurus</i> sp. | | | | | | | | | | | | x | | | | | | | | |
| Felidae gen. et sp. indet. | | | | | | | | | | | | | | | | | | | | x |
| <i>Hyaenictitherium wongi</i> | | | | | | | | | | | | | | | | | | | | x |
| <i>Ictitherium viverrinum</i> | | | | | | | | | | | | | | | | | | | | x |
| <i>Adcrocuta eximia</i> | | | | | | | | | | | | | | | | | | | | ? |
| <i>Dinocrocuta gigantea</i> | | | | | | | | x | - | - | - | x | - | - | x | | | | | |
| <i>Hipparion</i> sp.1 | x | | | | | | | | | | | | | | | | | | | |
| <i>Hipparion chiai</i> | | | | | | | | x | x | - | - | x | x | x | - | x | | | | |
| <i>Hipparion</i> sp.2 | | | | | | | | x | - | - | - | x | | | | | | | | |
| <i>Hipparion</i> sp.3 | | | | | | | | | | | | x | | | | | | | | |
| <i>Hipparion weihoense</i> | | | | | | | | x | - | - | - | x | - | - | x | | | | | |
| <i>Hipparion</i> sp.4 | | | | | | | | | | | | | | | | | | | | x |
| <i>Hipparion</i> cf. <i>H. hippidioides</i> | | | | | | | | | | | | | | | | | | | | x x |
| <i>Hipparion</i> sp.5 | | | | | | | | | | | | | x | | | | | | | |
| <i>Hipparion</i> sp.6 | | | | | | | | | | | | | | | | | | | | x |
| Chalicotheriidae gen. et sp. indet. | | | | | | | | x | | | | | | | | | | | | |
| <i>Stephanorhinus orientalis</i> | x | - | - | - | - | - | - | - | - | - | - | x | x | | | | | | | |
| cf. <i>Brachypotherium</i> sp. | | | | | | | | | | | | | | x | | | | | | |
| cf. <i>Chilotherium</i> sp. | x | | | | | | | | | | | | | | | | | | | |
| <i>Chilotherium gracile</i> | | | | | | | | | | | | | | | | | | | | x |
| <i>Chilotherium habereri</i> | | | | | | | | | | | | | | | | | | | | x |
| <i>Chilotherium</i> indet. | | | | x | | | | | | | | | | | | | | | | |
| <i>Acerorhinus paleosinense</i> | | | | | | | | | | | | | | | | | | | | x |
| <i>Acerorhinus</i> indet. | | | | | | | | | | | | x | | | | | | | | |
| <i>Chleuastochoerus stehlini</i> | | | | | | | | | | | | | | | | | | | | x x x x |
| <i>Microstonyx</i> indet. | | | | | | | | | | | | | | | | | | | | x |
| <i>Metacervulus</i> indet. | | | | | | | | | | | | x | | | | | | | | |
| <i>Cervavitus novorossiae</i> | | | | | | | | | | | | | | | | | | | | x |
| <i>Cervavitus</i> indet. | | | | | | | | | | | | | | | | | | | | x |
| <i>Procapreolus latifrons</i> | | | | | | | | | | | | | | | | | | | | x |
| <i>Paleotragus</i> cf. <i>P. decipiens</i> | | | | | | | | | x | - | - | - | x | | | | | | | |
| <i>Palaeotragus microdon</i> | | | | | | | | | | | | | | | | x | | | | x - x |
| <i>Schansitherium</i> cf. <i>S. tafelli</i> | | | | | | | | | | | | x | x | | | | | | | |
| <i>Gazella</i> sp.1 | | | | | | | | | | | | | | | | | | | | x x ? |
| <i>Gazella</i> sp.2 | | | | | | | | | | | | | | | | | | | | x x |
| <i>Gazella</i> sp.3 | x | | | | | | | | | | | | | | | | | | | |
| <i>Gazella</i> cf. <i>G. lydekkeri</i> | | | | | | | | | x | - | - | - | x | x | | | | | | |
| <i>Dorcadoryx triquetricornis</i> | | | | | | | | | x | - | - | - | x | x | | | | | | |

续表

| Taxa | Bahe Fm. | | | | | | | | | | | | | | Lantian Fm. | | | | |
|---|----------|-----|-----|-----|-----|-----|-----|----|-----|-----|----|----|----|----|-------------|-----|----|-----|-----|
| | L12 | L19 | L35 | L38 | L13 | L31 | L30 | S6 | L34 | L33 | L6 | S5 | S1 | S2 | S4 | L42 | S3 | L44 | S10 |
| cf. <i>Tragoreas</i> sp. | | | | | | | | | | | | | | | | | | | x |
| <i>Shaanxispira chowi</i> | | | | | | | | x | | | | | | | | | | | |
| ? <i>Shaanxispira</i> sp. nov. | | | | | | | x | - | - | x | x | | | | | | | | |
| <i>Protoryx</i> sp. nov. | x | | | | | | | | | | | | | | | | | | |
| <i>Protoryx</i> indet. | | | | | | | | | x | - | x | | | | | | | | |
| <i>Tetralophodon exoletus</i> | | | | | | | | x | - | - | - | x | | | | | | | |
| Talpidae gen. et sp. indet. | x | | | | | | | | | | | | | | | | | | |
| <i>Erinaceus</i> sp. | | | | | | | | | | | | | | x | | | | | |
| Soricidae gen. et sp. indet. 1 | x | x | | | | | | | | | | | | | | | | | |
| Soricidae gen. et sp. indet. 2 | | | | x | | | | | | | | | | | | | | | |
| ? <i>Pseudoaplodon</i> sp. | | | | | | | | | | | | | | | | | | | x |
| <i>Eutamias</i> sp. | | x | - | - | x | - | - | - | - | - | - | - | - | - | - | - | - | - | x |
| <i>Sciurotamias</i> sp. | | x | - | x | | | | | | | | | | | | | | | |
| Dipodidae gen. et sp. nov. | | x | | | | | | | | | | | | | | | | | |
| <i>Protolactaga major</i> | x | x | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | x |
| <i>Paralactaga</i> sp. | | x | | | | | | | | | | | | | | | | | |
| <i>Lophocricetus</i> cf. <i>L. gansus</i> | | x | | | | | | | | | | | | | | | | | |
| Cricetidae gen. et sp. nov. | x | x | - | x | - | - | - | - | - | - | - | - | - | - | - | - | - | - | x |
| <i>Myocricetodon</i> cf. <i>M. trenki</i> | x | x | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | x |
| Cricetidae gen. et sp. indet. | x | | | | | | | | | | | | | | | | | | |
| <i>Abudhabia</i> sp. nov. | x | x | - | - | x | - | - | - | - | - | - | - | - | - | - | - | - | - | x |
| <i>Progonomys</i> cf. <i>P. cathalai</i> | x | x | - | x | x | - | - | - | - | - | - | - | - | - | - | - | - | - | x |
| <i>Prosiphneus licenti</i> | | | | | | | | | | | | | | | | | | | x |
| <i>Typhlomys</i> sp. | | | | | | | | | | | | | | | | | | | x |
| Incertae familiae gen. et sp. indet. | | | | | x | | | | | | | | | | | | | | |
| <i>Ochotona</i> cf. <i>O. lagreli</i> | x | | | | | | | | | | | | | | | | | | |

L: new locality; S: locality of Liu et al. (1978)

Giraffidae Only two forms are represented in the new collection. One is *Paleotragus microndon*, known only from the basal Lantian Formation localities 42 and 44. The other form is only known from the Bahe Formation, from Loc. 33 and possibly Loc. 6. It is here tentatively assigned to *Schansitherium tafeli* based on the upper premolars, which are relatively brachyodont, rather than to *Samotherium*.

Bovidae A large bovid with long muzzle and square shaped upper molars known from the lowest horizon (Loc. 12) is thought to be close to *Protoryx*, which by measurements of the teeth, close to those from Locs. 30 and 6.

The puzzling *Gazella* from Loc. 31 appears to be close to *G. lydekkeri* from Pakistan (probably the Dhok Pathan at ca. 8.0Ma (Pilgrim 1937, figs. 35 ~ 39)). Chen (1997) regarded *G. gaudryi* as the most primitive gazelle of the Chinese Neogene, with round and relatively small horncores and primitive morphology of p4, while *Gazella* cf. *G. lydekkeri* from Loc. 31 shows some derived character states according to the evolutionary trends listed by Chen (1997), e. g. relatively large size, more laterally compressed horncores, short premolar row, and forward extension of the meta-

conid on p4, even metaconid-paraconid fusion.

The *Gazella* of Loc. 42 is very similar with *G. paotehensis* described by Teilhard and Young (1931) from Baode Lok. 109 in the size of its horn cores, but the latter species has longer tooth rows and more hypsodonty teeth. However, the *Gazella* from other Baode localities previously referred to *Gazella* sp. (? *paotehensis*) (Bohlin, 1935, 1939) fits well with our Lantian specimen by morphology and measurements.

The *Dorcadoryx* found mainly from Loc. 6 appears close to *D. triquetricornis* and may represent a new species of smaller size. The "*Gazella* sp. 2" (V 3129) described by Liu et al. (1978) from level 59s6 seems to belong to the species of *Dorcadoryx* known from Loc. 6.

Shaanxispira chowi was described by Liu et al. (1978). It has clockwise torsion of horn cores on the right, with two keels separating the concave and convex part along the horn cores.

Another large bovid, similar to *Shaanxispira* in its clockwise torsion of horn cores on the right, is present at localities 6 and 33. This large bovid has horn cores with round cross section and only one keel ascending from the inner side, pedicles not developed, the keel starting just from the frontal. The parietal is bent down to the facial level. The premolar row is relatively longer than in *S. chowi*.

There are also a few specimens of *Protoryx* from Locs. 6 and 34. The Lantian specimens differ from *Protoryx-Sinotragus* in that they are slightly smaller, the p4 lacks paraconid-metaconid fusion, the transverse metaconid crest of p4 sometimes appears to originate at its labial end posterior to the protoconid, the p4 anterolabial wall is less strongly aligned transversely and so on.

The structure or composition of the pecoran fauna of the Bahe Formation is quite similar to that of the Baode *Hipparion* fauna. However, the species and sometimes the genera in the two faunas are different. *Shaanxispira* for example looks like a less specialized version of *Plesiaddax* or *Umiatherium*. Such signs as there are, especially from the ? *Protoryx* sp. and *Shaanxispira*, suggest that the Lantian fauna predates the Baode one.

The affinity of the pecorans in either Chinese fauna with those of the European and southwest Asian late Miocene is less close than implied by Bohlin in his detailed and pioneering works. Antilopini with anticlockwise-spiralled horns are lacking in both Bahe and Baode faunas and Boselaphini are very rare. Many fossils of large giraffids in either Chinese fauna may yet be found to belong to *Schansitherium* and not *Samotherium*. *Shaanxispira* and *Dorcadoryx* are unknown outside China.

Equidae Only very preliminary remarks are offered here, pending later detailed study. Altogether about six morphological groups were recognized in a rough survey of metapodial and craniodental evidence.

Locality 12 has one or possibly two (dental) morphs. One is large with complicated fossette ornamentation, the other is smaller and with simple fossette ornamentation. The material is insufficient for more detailed conclusions.

Locality 49 has a large male skull possibly corresponding to *H. weihoense* described from the Lantian area by Liu et al. (1978). Such large material is also known from Loc. 4.

Locality 6 has three metapodial morphs: large & shallow, medium & deep, and tiny. Three morphs are seen in the skulls and teeth, the larger corresponding to the type of *H. chiai* described from same area by Liu et al. (1978). The medium morph has somewhat more plications on its cheek teeth. The smaller male adult individual (P2 ~ M3 length 137.8mm) with a single pli caballin and simple fossette ornamentation is obviously different from the other material and may represent a new species.

Locality 30 has metapodial material representing the "medium & deep" morph known from Loc. 6. There is only juvenile craniodental material.

Locality 42 has two morphs with very long and slender metapodials—one with a narrow hoof and one with a broad hoof. The skulls from Loc. 42 seem a good match for the narrow-hoofed form, which might represent *H. hippidioidus*, described from Qingyang by Sefve (1927) and known to

have slender metapodials (Qiu et al. , 1987). The broad-hoofed morph is expected to have a larger skull than those presently known from the locality.

Rhinocerotidae Rhinoceroses are moderately common in both the Bahe and Lantian Formations. Locality 12 in the lowermost level of the Bahe Formation has yielded *Stephanorhinus orientalis* and a previously unrecognized species also known from Baode Localities 44 and 108, tentatively referable to cf. *Chilotherium* sp. *Stephanorhinus orientalis* is also known from Loc. 6, accompanied there by an indeterminate species of *Acerorhinus*, and, possibly, a small *Chilotherium*. A small *Chilotherium* referred by Liu et al. (1978) to *C. gracile* is known from a comparable level (locality S5) in the Bahe Formation. The same locality has also yielded fragmentary dental remains of a very large rhinoceros referred by Liu et al. (1978) to ? *Brachypotherium* sp. Locality 42 has yielded *Acerorhinus palaeosinensis* and *Chilotherium*, most probably *Chilotherium haberei* represented by dental remains from the Lantian Loc. S3 (Liu et al. , 1978). It is not possible to demonstrate that the *Acerorhinus* and *Chilotherium* material of the upper Bahe and the Lantian represents single evolving lineages, but this certainly seems the most plausible interpretation. The ? *Chilotherium* from Loc. 12 shows some derived *Chilotherium* characters in the skull and dentition combined with a retention of the normal rhinoceros jaw joint, otherwise modified in species of the genus. It is difficult to assess its systematic position beyond the obvious fact that it must either be close to the origin of *Chilotherium*, or else represent a convergent evolution of a *Chilotherium*-like morphology.

Biogeographically all rhinoceros species have northern Eurasian affinities except ? *Brachypotherium* sp., which (if correctly identified from the very incomplete material) has its closest coeval relatives in South Asia. By dental wear, all species appear to have been browsers or mixed feeders. No clear difference in dental wear can be shown between the rhinoceroses of the Bahe and Lantian formations.

3.2 Small mammals

The Bahe Formation has delivered 19 species of small mammals from 10 families. At least one third are new genera of Dipodidae, Cricetidae and incertae familiae, and three genera are new for the fossil record in China (*Abudhabia*, *Myocricetodon*, and *Progonomys*) (Qiu et al. , in press). The association represents a new assemblage in the sequence of micromammalian faunas of the Chinese Neogene, with an early late Miocene age, correlative roughly with the late Vallesian-early Turonian or MN10-11 of western Europe. The small mammal taxa recovered from the Lantian Formation is small. Recently finding of *Typhlomys* sp. from Loc. 42 (represented by only a single m2) is very interesting for its ecological significance. This genus is now distributed in South China and North Viet Nam, in tropical and subtropical mountain forest (Zhang, 1997). Fossil materials were only found from Lufeng (late Miocene) (Qiu et al. , 1985) and Wushan (early Pleistocene) (Huang et al. , 1991).

4 Discussion

At the time of writing, there are totally 65 species found from Late Neogene sediments (Bahe and Lantian Formation) from the Lantian area including the old collection of the 1960's. Of these species, 20 are from the Lantian Formation, 45 from the Bahe Formation.

Our new fossil discoveries are combined with the results of Liu et al. (1960, 1978) in Table 1. It is immediately clear that there is a striking lack of faunal change within the Bahe Formation, and that the Bahe/Lantian boundary appears to correspond to a major faunal turnover. Unfortunately the lack of good localities in the uppermost part of the Bahe Fm prevents a precise dating of the faunal turnover. It must have preceded the change in lithology from fluvial to aeolian by an unknown but probably not very long interval. That it could not coincide with or postdate the lithological change is shown clearly by Loc. 42, with a post-turnover fauna within the lithological transition. Other localities that have delivered the same faunal assemblage include Loc. 44 and the old locality S3, possibly identical with Loc. 42. All these faunas appear to represent the boundary zone and thus

formally the lowermost part of the Lantian Fm. The subsequent faunal evolution within the Lantian Formation remains unknown in this area.

Our results thus support part of the scenario presented by Liu et al. (1978), in particular the unexpected shift towards more closed conditions in the latest Miocene. It should be known that the "lower Bahe" of Liu et al. (1960) was represented by the locality 59S10. The fossils recovered from this locality include *Hipparion* sp. (close to *Hipparion hippidiodus*), *Chleuastochoerus stehlini*, *Adcrocuta eximia*, *Gazella* cf. *G. gaudryi*, and ?*Tragoreas* sp. (close to the *Dorcacoryx paleosinense* by size). Given the uniform nature of the faunas recovered from the Bahe Fm, this assemblage strongly suggests that the locality in fact belongs in the Lantian Fm. Our attempts to identify locality 59S10 in the field were not successful, but an instance of a major slump including a fossil accumulation similar to that of Loc. 42 was discovered in a topographically low position during our fieldwork (Loc. 44). If this re-interpretation is accepted, the scenario of faunal change reported by Liu et al. (1978) is reduced to a single episode of change from open to closed conditions.

The mammal fossils recovered from the lowest part of the Lantian Formation includes *Hyaenictitherium wongi*, *Ictitherium viverrum*, *Adcrocuta eximia*, *Cervavitus novorossiae*, *Procapreolus latifrons*, *Gazella* sp. (cf. *paotehensis*), *Paleotragus microdon*, *Chleuastochoerus stehlini*, *Hipparion hippidiodus*, *Chilotherium habereri*, and *Acerorhinus paleosinense*, etc. The assemblage fits well with the Baode Red Clay fauna recovered from different tunnels and localities. There is no good match in China or elsewhere for the faunal assemblage recovered from the Bahe formation, which represents a time bracketed by the arrival of hipparionine horses in the Old World at about 11 Ma (García et al., 1997) and probably (see below) by the climatic change represented by the beginning of Red Clay deposition in the central Loess Plateau, dated at 7 ~ 8 Ma (Ding et al., 1998; Qiang et al., 2001). Our results therefore suggest that the original concept of a Bahean Land Mammal Age (Li et al. 1984), predating the Baodean LMA, was substantially correct and could be resurrected.

The similarity of the fossil mammals from the various Red Clay deposits (e. g., Lantian, Baode and Fugu) indicates that this mammal community was widespread in North China in the latest Miocene. The beginning of Red Clay sedimentation appears to have been regionally diachronous within North China. The Lantian sequence (the only known continuous and fossiliferous record that includes the event) demonstrates that the faunal change does not necessarily correspond locally to the lithological transition. It is not known at present from the fossil record whether the faunal turnover was synchronous over this area, but this appears almost inevitable, given its small size in relation to the typical geographic ranges of large mammals today. The most parsimonious interpretation of the relationship would be that the faunal change records an overall global shift in climate, while the local change in sedimentology was also affected by local conditions.

The Lantian sequence demonstrates unequivocally that the direction of environmental change inferred from the mammal faunas was opposite to that recorded from western Eurasia and North America (Janis, 1993), towards more closed habitats. We would like to predict that the faunal change will be found to be related to the beginning of increased summer rainfall in East Asia that would have resulted from intensified summer monsoon circulation, suggested to have taken place at about 8 Ma (Ding et al., 1999; An et al., 2001).

5 Conclusion

1) There exists clear evidence of faunal change in both taxonomy and ecology at a time preceding the Bahe and Lantian Fm boundary by an unknown but probably short interval.

2) Based on the new findings, it would be possible to resurrect the Bahean Land Mammal Age for the earlier part of the late Miocene of China.

3) The Baode *Hipparion* Fauna, though not studied biostratigraphically, is seen by stratigraphic superposition in Lantian to be later than the faunas from the Bahe Formation that predate the turr

over event. Hence the traditional Baodean Land Mammal Age could only represent the later part of the late Miocene.

4) The Lantian faunas show a single, well defined turnover event suggesting a shift from open towards closer habitats within the late Miocene.

5) It appears possible to use fossil mammal data to relate the regional-scale environmental history of North China to global, tectonically driven climate changes.

Acknowledgements We thank all colleagues and students who participated in the Lantian Project: Zhou Wei, Cui Nin from IVPP; Lena Sel anne, Kari Lintulaakso and Jussi Kenkil a from the University of Helsinki; Ki Andersson and Maria Bj ornsdotter from the Swedish Museum of Natural History; Dr. Linda Ayliffe from the University of Utah; Dr. Wulf G se and Mulugeta Fessaha from the University of Texas at Austin; and Dr. Philip Gbbard from the University of Cambridge. This work was supported by the Academy of Finland (grants no. 44026 and 34080); several exchange grants between the CAS and Academy of Finland; and the Finnish Cultural Foundation and Graduate School in Environmental Geology to Anu Kaakinen.

References

- An Z S, Kutzbach J E, Prell W L et al., 2001. Evolution of Asian monsoons and phased uplift of the Himalaya-Tibetan Plateau since Late Miocene times. *Nature*, **411**:62 ~ 66
- Bohlin B, 1935. Cavicornier der *Hipparion*-fauna Nord-Chinas. *Pal Sin*, Ser C, **9**(4):1 ~ 164
- Bohlin B, 1939. *Gazella* (*Protetraceros*) *gaudryi* (Schlosser) and *Gazella dorcadoides* Schlosser. *Bull Geol Inst Upsala*, **28**:79 ~ 112
- Chen G F (陈冠芳), 1997. The genus *Gazella* Blanville, 1816 (Bovidae, Artiodactyla) from the Late Neogene of Yushe Basin, Shanxi Province, China. *Vert PalAsiat* (古脊椎动物学报), **35**(4):233 ~ 249 (in Chinese with English summary)
- Chow M C (周明镇), 1978. Tertiary mammalian fauna of the Lantian District, Shensi. *Prof Pap Strati Paleontol* (地层古生物论文集), **7**:98 ~ 108 (in Chinese)
- Ding Z L, Sun J M, Liu T S et al., 1998. Wind-blow origin of the Pliocene red clay formation in the Chinese Loess Plateau. *Earth and Planetary Science Letters*, **161**:135 ~ 143
- Ding Z L, Xiong S F, Sun J M et al., 1999. Pedostratigraphy and paleomagnetism of a ~7.0 Ma eolian loess-red clay sequence at Lingtai, Loess Plateau, north-central China and the implications for paleomonsoon evolution. *Palaeogeogr Palaeoclimatol palaeoecol*, **152**:49 ~ 66
- Fortelius M, Solounias N, 2000. Functional characterization of Ungulate molars using the Abrasion-Attrition wear gradient: a new method for reconstructing paleodiets. *Am Mus Novit*, (3301):1 ~ 36
- Garc a M, Cabrera L, Agust  j et al., 1997. Old World first appearance datum of "*Hipparion*" horses: Late Miocene large-mammal dispersal and global events. *Geology*, **25**:19 ~ 22
- Gao Z T, Peng S Z, Hao Q Z et al., 2001. Origin of the Miocene-Pliocene Red Earth Formation at Xifeng in Northern China and implications for paleoenvironments. *Palaeogeogr Palaeoclimatol Palaeoecol*, **170**:11 ~ 26
- Huang W B (黄万波), Fang Q R (方其仁) et al., 1991. Wushan Hominid Site. Beijing: China Ocean Press. 67 ~ 69 (in Chinese with English summary)
- Janis C M, 1993. Tertiary mammal evolution in the context of changing climates, vegetation, and tectonic events. *Annu Rev Ecol Syst*, **24**:467 ~ 500
- Li C K (李传夔), Wu W Y (吴文裕), Qiu Z D (邱铸鼎), 1984. Chinese Neogene: subdivision and correlation. *Vert PalAsiat* (古脊椎动物学报), **22**(3):163 ~ 178 (in Chinese with English summary)
- Liu D S (刘东生), Ding M L (丁梦麟), Gao F Q (高福清), 1960. Tertiary stratigraphic sections between Xi'an and Lantian. *Geology Science* (地质科学), **4**:200 ~ 208 (in Chinese)
- Liu D S (刘东生), Li C K (李传夔), Zhai R J (翟人杰), 1978. Pliocene vertebrates of Lantian, Shensi. Tertiary mammalian fauna of the Lantian District, Shensi. *Prof Pap Strati Paleontol* (地层古生物论文集), **7**:149 ~ 200 (in Chinese)
- Liu X M, Xu T C, Liu T S, 1988. The Chinese loess in Xifeng, II. A study of anisotropy of magnetic susceptibility of loess in Xifeng. *Geophysical J*, **92**:349 ~ 353
- Lu H, Vandenbergh J, An Z S, 2001. Aeolian origin and palaeoclimatic implications of the 'Red Clay' (North China) as evidenced by grain-size distribution. *J Quat Sci*, **16**:89 ~ 97
- Pilgrim G E, 1937. Siwalik antelopes and oxen in the American Museum of Natural History. *Bull Am Mus Nat Hist*, **72**:729 ~ 874
- Qiang X K, Li Z X, Powell C MacA et al., 2001. Magnetostratigraphic record of the Late Miocene onset of the East Asian monsoon, and Pliocene uplift of northern Tibet. *Earth and Planetary Letters*, **187**:83 ~ 93
- Qiu Z D (邱铸鼎), Han D F (韩德芬), Qi G Q (祁国琴) et al., 1985. A preliminary report on a micromammalian assemblage from the Hominoid locality of Lufeng, Yunnan. *Acta Anthropol Sin* (人类学学报), **4**(1):13 ~ 33 (in Chinese with English summary)

- Qiu Z X, 1990. The Chinese Neogene Mammalian Biochronology —Its correlation with the European Neogene Mammalian Zonation. In: Lindsay E H, Fahlbusch V, Mein P eds. European Neogene Mammal Chronology. New York: Plenum Press. 527 ~ 556
- Qiu Z X (邱占祥), Qiu Z D (邱铸鼎), 1990. Neogene local mammalian faunas: succession and ages. *J Stratigr (地层学杂志)*, **14**(4):241 ~ 260(in Chinese with English summary)
- Qiu Z X, Qiu Z D, 1995. Chronological sequence and subdivision of Chinese Neogene mammalian fauna. *Paleogeogr Paleoclimatol Paleocol*, **116**:41 ~ 70
- Qiu Z X(邱占祥), Huang W L(黄为龙), Guo Z H(郭志慧), 1987. The Chinese hipparionine fossils. *Pal Sin(中国古生物志)*, New Ser C, **25**:1 ~ 250 (in Chinese with English summary)
- Qiu Z X (邱占祥), Xie J Y(谢骏义), Yan D F(阎德发), 1988. Discovery of the skull of *Dinocrocota gigantean*. *Vert PalAsiat (古脊椎动物学报)*, **26**(2):128 ~ 138(in Chinese with English summary)
- Sefve I, 1927. Die Hipparionen Nord-Chinas. *Pal Sin*, Ser C, **4**(2):1 ~ 93
- Sun D H, An Z S, Shaw J et al., 1998. Magnetostratigraphy and paleoclimatic significance of late Tertiary aeolian sequences in the Chinese Loess Plateau. *Geophysical Journal International*, **134**:207 ~ 212
- Sun D H, Liu D S, Chen M Y et al., 1997. Magnetostratigraphy and palaeoclimate of Red Clay sequences from Chinese Loess Plateau. *Science in China*, Ser D, **40**:337 ~ 343
- Teilhard de Chardin P, Young C C, 1931. Fossil mammals from Northern China. *Pal Sin*, Ser C, **9**(1):1 ~ 66
- Tleuberina P A, 1982. Late Neogene fauna of SE Kazakhstan. *Alma-Ata: Izdatelstvo "Nauka" Kazakhskoi SSR*. 73 (in Russian)
- Xue X X, Zhang Y X, Yue L P, 1995. Discovery and chronological division of the *Hipparion* fauna in Laogaochuan Village, Fugu County, Shaanxi. *Chinese Sci Bull*, **40**(11):926 ~ 929
- Zdansky O, 1924. Fundorte der *Hipparion* Fauna um Paot-Te-Hsien in NW-Shansi. *Bull Geol Surv China*, **5**:69 ~ 81
- Zhang R Z (张荣祖), 1997. Distribution of mammalian species in China. Beijing: China Forestry Publishing House. 181 ~ 182 (in Chinese with English summary)
- Zhang Y P (张玉萍), Huang W B(黄万波), Tang Y J(汤英俊) et al., 1978. Cenozoic of the Lantian Area, Shaanxi. *Mem Inst Vert Paleontol Paleoanthropol, Acad Sin, Spec Publ A (中国科学院古脊椎动物与古人类研究所甲种专刊)*, (14):1 ~ 64 (in Chinese)
- Zhang Y X (张云翔), Xue X X (薛祥熙), 1996. New materials of *Dinocrocota gigantea* found in Fugu County, Shaanxi Province. *Vert PalAsiat (古脊椎动物学报)*, **34**(1):18 ~ 26(in Chinese with English summary)