

亚洲古近纪早期的年代学 和哺乳动物群更替¹⁾

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摘要:对广东南雄盆地、江西池江盆地、安徽潜山盆地、湖南衡阳盆地和内蒙古二连盆地古新世和早始新世沉积物进行的生物地层学、化学地层学和磁性地层学研究,第一次给亚洲早古近纪地层框架提供了严格的年代限定。亚洲古新世和早始新世地层划分为4个生物年代单位(陆生哺乳动物期),从老到新为上湖期、浓山期、格沙头期和伯姆巴期4个亚洲陆生哺乳动物期。南雄盆地古地磁数据显示上湖期的底界约位于C29r的上2/3位置。南雄盆地的古地磁资料及池江盆地最新的古地磁和同位素结果显示上湖-浓山期界线在C27n的上部和C26r的下部之间,接近C27n-C26r转换界面。这一记录支持将上湖-浓山期的界线与北美陆生哺乳动物期中的Torrejonian-Tiffanian期以及海相记录中丹尼-塞兰特期(Danian-Selandian)的界线相对比。二连盆地古地磁和同位素研究表明典型的格沙头动物群延续至C24r,并且可能向下延伸至C25r和C26n。南雄盆地的记录指示浓山组和古城村组可能相当于C26r的上部。这些结果表明亚洲哺乳动物分期中的浓山-格沙头期的界线可能在北美哺乳动物分期的Tiffanian期中。衡阳盆地的古地磁和同位素证据指示,以短暂的碳同位素漂移为标志的古新世-始新世界线出现在栗木坪组和岭茶组之间,位于C24r中,与海相记录中的坦尼特-伊普里斯期(Thanetian-Ypresian)界线一致。伯姆巴期岭茶动物群的时代似乎与北美Wasatchian-0带的动物群可以比较。上湖期和浓山期动物群主要由亚洲特有的动物组成。发生在上湖期和浓山期界线处的动物群更替,与北美Torrejonian-Tiffanian期界线以及丹尼-塞兰特期界线一致。在相隔很远的生态系统上的这种巧合,可能反映出各自独立的对气候变化的生态和/或进化上的响应。格沙头动物群的地方性色彩更弱,有与北美Clarkforkian期动物群共有的属一级分类单元。伯姆巴动物群是全球性的。现生哺乳动物各目在格沙头-伯姆巴期界线处突然出现,与北美和欧洲的记录一致,显示动物群的更替与古新世-始新世界线处短暂出现的全球变暖事件(又称古新世-始新世高温事件)有关。

关键词:亚洲,古新世,早始新世,年代学

中图法分类号:Q915.87, P534.611 **文献标识码:**A **文章编号:**1000-3118(2011)01-0001-28

1) 国家重点基础研究发展计划项目(编号:2006CB806400)资助。

收稿日期:2009-10-24

ASIAN EARLY PALEOGENE CHRONOLOGY AND MAMMALIAN FAUNAL TURNOVER EVENTS

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Abstract Biostratigraphic, chemostratigraphic, and magnetostratigraphic studies of the Paleocene and early Eocene sediments in the Nanxiong Basin of Guangdong, Chijiang Basin of Jiangxi, Qianshan Basin of Anhui, Hengyang Basin of Hunan, and Erlian Basin of Nei Mongol, China, provide the first well-resolved geochronological constraints on the stratigraphic framework for the early Paleogene of Asia.

Asian Paleocene and early Eocene strata are subdivided into four biochronological units (Land Mammal Ages). From oldest to youngest, they are the Shanghuan, the Nongshanian, the Gashatan, and the Bumbanian Asian Land Mammal Ages (ALMA). Paleomagnetic data from the Nanxiong Basin indicate that the base of the Shanghuan lies about 2/3 the way up Chron C29r. Nanxiong data and recent paleomagnetic and isotopic results from the Chijiang Basin show that the Shanghuan-Nongshanian ALMA boundary lies between the upper part of Chron C27n and the lower part of Chron C26r, close to the Chron C27n-C26r reversal. This record favors a correlation of Shanghuan-Nongshanian ALMA boundary to the Torrejonian-Tiffanian North American Land Mammal Age (NALMA) boundary and to the Danian-Selandian stage boundary in the marine record. The paleomagnetic and isotopic data from the Erlian Basin show that typical Gashatan faunas persist into Chron C24r and may range into Chron C25r and possibly C26n, and the records from the Nanxiong Basin indicate that both Nongshan and Guchengcun formations may correlate to the upper part of Chron C26r. These results would imply that the Nongshanian-Gashatan ALMA boundary may correlate within the Tiffanian NALMA. The paleomagnetic and isotopic evidence from the Hengyang Basin indicates that the transient carbon isotope excursion that marks the Paleocene-Eocene boundary is present between the Limuping and Lingcha formations, and the boundary is placed at the uppermost reversed polarity interval correlated to Chron C24r and to the Thanetian-Ypresian stage boundary in the marine record. The Bumbanian Lingcha fauna seems to correlate with the Wasatchian-0 faunal zone of North America to within $\sim 10^4$ yr.

Both Shanghuan and Nongshanian faunas are mainly composed of Asian endemic taxa. The coincidence of faunal turnover at the Shanghuan-Nongshanian boundary with the Torrejonian-Tiffanian boundary and Danian-Selandian stage boundary in far separated ecosystems may indicate independent ecologic and/or evolutionary response to climatic changes. The Gashatan fauna shows less endemism and has taxa shared with those of the Clarkforkian NALMA in North America at the generic level. The Bumbanian fauna is cosmopolitan. A sudden appearance of modern mammalian orders at the Gashatan-Bumbanian boundary is the same pattern as observed in North America and Europe, indicating the faunal turnover is related to the transient global warming event at the Paleocene-Eocene boundary known as the Paleocene-Eocene Thermal Maximum (PETM).

Key words Asia, Paleocene, early Eocene, chronology

1 Introduction

The early Paleogene was a critical period in earth history. The earth underwent a series of severe environmental changes from the end of the Cretaceous to the end of the Paleocene, and witnessed the first episode of important biotic changes of the Cenozoic Era. Paleoceanographic records from deep-sea cores indicate a major climate cooling during the Maastrichtian (Li and Keller, 1998; MacLeod and Huber, 2005). The early Paleogene is characterized by a pro-

nounced trend of climate warming (Zachos et al., 2001), and by a gradual restoration of globally equable climates (Berggren and Aubry, 1998; Berggren et al., 1998). Throughout the early Paleogene, these long-term warming trends were punctuated by a series of more abrupt and/or transient climatic and environmental changes. The first step of the warming trend occurred near the Danian-Selandian transition (Guasti et al., 2006). A peak in iron concentration and magnetic susceptibility found in a deep-sea core at the top of Chron C27n during this transition has been referred to as the “Top Chron C27n Event” (Westerhold et al., 2008). The next abrupt environmental change transpired at the Selandian-Thametian transition. In the marine record, this event is characterized by a gradual shift from relatively cooler mesotrophic to warmer oligotrophic conditions near the base of Chron C26n (Bernaola et al., 2007; Bralower et al., 2006), and by an outstanding peak in Fe intensity (Westerhold et al., 2008). This event is referred to as MPBE (Mid-Paleocene Biotic Event, Bernaola et al., 2007; Bralower et al., 2006; Zachos et al., 2004), or ELPE (Early-Late Paleocene Event, Westerhold et al., 2008). At the end of Paleocene, a short-term (100 ~ 200 ky) climatic anomaly superimposed on longer-term (5 ~ 7 my) warming is recorded from deep-sea cores. This warming anomaly coincides with a marked negative shift in $\delta^{13}\text{C}$ values of marine carbonates (Kennett and Scott, 1991; Thomas and Shackleton, 1996). The presence of this negative shift in continental records (Koch et al., 1992, 1995) suggests a significant global carbon cycle perturbation coupled with global climatic warming during the Paleocene-Eocene transition (PETM, Paleocene-Eocene Thermal Maximum, Zachos et al., 2003). On land in the northern hemisphere, the PETM is closely associated with a prominent biotic events, at which the “archaic” eutherian mammal communities of the Paleocene are rapidly replaced by Eocene communities dominated by modern mammalian orders.

Many significant morphologically primitive Paleocene and early Eocene mammalian fossils have been discovered in Asia during the last forty years. Some of these fossils indicate that Asia was an important center for the origin and early evolution of several of the modern mammalian orders that first appeared elsewhere at the PETM (e. g. Beard, 1998). Asian early Paleogene mammal fossils were first found in the Nemegt Basin of Mongolia (Fig. 1-15) and the Erlian Basin of China (Fig. 1-14) by the Central Asiatic Expedition of the American Museum of Natural History in 1920s. One of the results from these expeditions was the discovery of a late Paleocene mammalian fauna, the Gashato Fauna (Matthew and Granger, 1925; Matthew et al., 1929). The expeditions in that region have been continued by the former academies of sciences of the Union of Soviet Socialist Republics and Poland, and Mongolian Academy of Science to the Nemegt (Dashzeveg, 1988; Kielan-Jaworowska, 1969; Kielan-Jaworowska and Dovchin, 1969; Szalay and McKenna, 1971), and by the Institute of Vertebrate Paleontology and Paleoanthropology (IVPP), Academia Sinica (now Chinese Academy of Sciences) to the Erlian, since the 1950s (Bowen et al., 2005; Chow et al., 1976; Chow and Qi, 1978; Meng et al., 1998, 2007). Another important breakthrough in the study of Asian early Paleogene strata was the discovery of a large number of earlier Paleocene and early Eocene fossils from China, especially southern China, during 1960-70s, by IVPP expeditions. These earlier Paleocene mammal fossils were discovered in several basins, including the Nanxiong Basin, Guangdong (Fig. 1-1) (Chang and Tung, 1963; Zhou et al., 1977), Chijiang Basin, Jiangxi (Fig. 1-3) (Tong et al., 1976, 1979; Zheng et al., 1973), Qianshan Basin, Anhui (Fig. 1-5) (Qiu et al., 1977), and others. The best preserved early Eocene mammal fossils were found in the Hengyang Basin, Hunan (Fig. 1-18) (Bowen et al., 2002; Li et al., 1979; Ting, 1995; Ting et al., 2003; Young, 1944), Erlian Basin, Nei Mongol (Fig. 1-14) (Bowen et al., 2005; Chow and Qi, 1978; Meng et al., 1998, 2007), and Nemegt Basin, Mongolia (Fig. 1-15) (Dashzeveg, 1988). Early Eocene mammals have also been discovered from Kyrgyzstan (Fig. 1-29), Kazakhstan (Fig. 1-30), Pakistan (Fig. 1-31, 32, 33), and India (Fig. 1-34) (Averianov and

Godinot, 1998; Gingerich et al., 1998; Thewissen et al., 2001). These findings provide significant evidence not only for the study of the early evolutionary history of mammals, but also for the intercontinental correlation of Asian early Paleogene records.



Fig. 1 Map showing the major Paleocene and early Eocene sites in Asia

Asian Paleocene and early Eocene strata are mainly composed of terrestrial deposits. Fossil mammals have become the primary tool for the subdivision of these strata and for their stratigraphic correlation. Romer (1966) first proposed the term Gashatan to represent the Asiatic Paleocene Age, correlating it to the Thanetian of Europe, Tiffanian of North America, and the Riochican of South America. A series of Paleocene and early Eocene Asian land mammal ages have been proposed since then (Dashzeveg, 1988; Li and Ting, 1983), including from the oldest to the youngest: the Paleocene Shanghuan, Nongshanian, Gashatan, and the early Eocene Bumbanian. However, Asian Paleocene and early Eocene strata have long been unconstrained radiometrically, and the land mammal age framework is poorly correlated to the geological time scale. Therefore, the correlation of Asian land mammal ages within Asia and with those of Europe and North America varied (Li and Ting, 1983; Russell and Zhai, 1987; Ting, 1998; Tong et al., 1995; Wang et al., 1998). To provide evidence for precise age determination of

these strata and their intercontinental correlation, we have employed biostratigraphic, chemostratigraphic, and magnetostratigraphic studies on the strata from five selected basins since year 2000, including the Nanxiong (Fig. 1-1), Chijiang (Fig. 1-3), Qianshan (Fig. 1-5), Hengyang (Fig. 1-18), and Erlian basins (Fig. 1-14), China. Detailed descriptions of new fossils and analyses of isotopic and paleomagnetic samples were reported in previous papers (Bowen et al., 2002, 2005; Clyde et al., 2008, 2010; Meng et al., 2004, 2005, 2007; Ting et al., 2003, 2004, 2007). In this paper, we summarize the biotic, isotopic, and paleomagnetic results from these basins, provide a geochronologically constrained Asian Paleocene and early Eocene biostratigraphic framework correlated to the geological time scale, and examine the faunal turnover events in the context of global environmental changes.

2 Materials and methods

Field trips were conducted for fossil and rock sample collecting to the Hengyang Basin in 2000, the Chijiang Basin in 2003, the Nanxiong and Qianshan basins in 2005, and the Erlian Basin since 2002. The team was typically divided into three coordinated groups: fossil collecting, isotopic sampling, and paleomagnetic sampling. In each basin, we measured stratigraphic sections, collected isotopic and paleomagnetic samples along the measured sections, and tied the fossil sites to the paleomagnetic and isotopic sites in the measured section via lithostratigraphic correlation. New fossils found during the trip were prepared and studied immediately in IVPP after the trip, and published separately. The fossil list for faunal analysis is compiled from up-to-date published papers (Appendix 1, 2, as of February, 2008). The faunal correlation is completed by using the sequential agglomerative hierarchical nested cluster analysis (SAHN) (Sneath and Sokal, 1973) based on the newly compiled faunal list (Appendix 2). We first compute a variety of similarity and dissimilarity coefficients for the raw data matrix of locality faunal lists. A similarity/dissimilarity matrix (size = 216 mammalian taxa \times 40 faunas) was built from presence/absence (1,0) data at the generic level by using a Jaccard association coefficient. We then clustered the data by reordering the similarity matrix and by using an unweighted pair-group average clustering method (UPGMA) from SAHN to build a phenogram, which is computed by the NTSYSpc 2.2 computer program (Rohlf, 2005). The FIND option in SAHN found a total of 36 tied trees during the clustering process, which may change clustering. Since SAHN methods are not well designed to treat ties found in the process, we used the cophenetic value and the matrix comparison program as a reference to select a tree that summarizes the 36 tied trees. To measure the goodness-of-fit of the clustering analysis, we used the COPH module to compute the matrix of cophenetic (ultrametric) values and then used the MXCOMP Matrix comparison program to compute the correlation between the cophenetic value matrix and the original matrix being clustered. The result, matrix correlation $r=0.91328 \sim 0.91973$, indicates that the cluster analysis is a good fit. The tree with the highest matrix correlation $r=0.91973$ is chosen for publication.

Paleosol carbonate nodules and chemostratigraphic sediment samples (cm- to dm-sized blocks) for total organic carbon concentration (TOC) and bulk $\delta^{13}\text{C}$ analysis were collected from freshly exposed rock surfaces at the same stratigraphically-keyed localities where paleomagnetic samples were taken. Full descriptions of the methodological and data reduction procedures are described in Bowen et al. (2002) and Clyde et al. (2008). Briefly, micritic carbonate was drilled from the polished surface of paleosol carbonate nodules to ensure minimal contamination by diagenetic spar. Sediment samples for organic carbon analysis were prepared by removing surficial material from sample blocks and treating the samples with 10% HCl to remove carbonate and dichloromethane to remove soluble organics. Samples were analyzed at the University of California, Santa Cruz, stable isotope laboratory by the phosphoric acid reaction method

using a common acid bath device and dual inlet isotope ratio mass spectrometry (carbonates) or by elemental analysis-isotope ratio mass spectrometry (organics). All carbon isotope data are reported relative to the VPDB standard.

Paleomagnetic samples were taken as oriented hand samples and later cut into ~2.5 cm cubes or were drilled as oriented 1-inch diameter cores. All analyses were conducted in the paleomagnetics laboratory at University of New Hampshire using HSM2 SQUID cryogenic magnetometer Molspin tumbling AF demagnetizer, and a ASC Model TD48-SC thermal demagnetizer. Remanence components were determined by least-squares analysis and site statistics were determined using the methods of Fisher (1953). Virtual Geomagnetic Pole (VGP) positions were calculated for each site and these were averaged to calculate a mean paleomagnetic pole for the entire study. Stratigraphic sections were measured using Jacob staff and abney level. GPS location and stratigraphic level were determined for each sample site.

3 Early Paleogene chronology and mammalian faunal turnover events

3.1 Cretaceous-Tertiary boundary and the Shanghuan Land Mammal Age

The Cretaceous-Tertiary boundary in Asia is best preserved in the Nanxiong (Nanhsiung) Basin, Guangdong, China — a classic site producing a complete sequence from the late Cretaceous to the late Paleocene. The basin is located in the northern part of Guangdong (25°00' ~ 25°10'N, 114°15' ~ 114°30'E, Fig. 1-1). The first Paleocene fossil in the basin, a turtle fragment, was reported by Young and Chow (1962), and mammalian fossils were subsequently found by Chang and Tung (1963). The Cretaceous strata are named the Nanxiong (Nanhsiung) Group (Chang and Tung, 1963), and the Paleocene strata are subdivided into three formations, from the oldest to the youngest: the Shanghu, Nongshan, and Guchengcun (Tong et al., 1976; Zhang, 1984, 1992). The Nanxiong Group (Nanxiong Formation of Cheng et al., 1973, Tong et al., 1976, and Zhou et al., 1977) was subdivided into lower Yuanpu and upper Pingling formations by Zhao et al. (1991). It yields dinosaurs *Tarbosaurus* sp., *Nanshiungosaurus brevispinus*, and *Microhadrosaurus nanshiungensis* (Dong, 1979), and eggs, *Shixingoolithus erbeni*, *Stromatoolithus pinglingensis*, etc. (Zhao et al., 1991). The precise position of the Cretaceous-Paleogene boundary has long been debated, depending on different criteria (Erben et al., 1995; Tong et al., 1976, 2002; Yu et al., 1990; Zhang, 1992; Zhao et al., 1991, 2002). Based on mammalian fossils, the Cretaceous-Paleogene boundary is placed between the Nanxiong Formation containing dinosaur and eggs and the Shanghu Formation containing relatively common mammals (Chang and Tung, 1963; Cheng et al., 1973; Tong et al., 1976; Zhou et al., 1977). Zhao et al. (1991) suggested the boundary should be placed at the contact of the Pingling Formation that produces dinosaur egg-shells and Shanghu Formation that produces mammalian fossils. These two formations are separated by a 1 meter thick conglomeratic sandstone (Tong et al., 2002). Stets et al. (1996) proposed, based on palynological data, to place the boundary within the Pingling Formation at a position ~90 m below that of Zhao et al. (1991). New paleomagnetic data from the Nanxiong Basin (Clyde et al., 2010) indicate that the bottom of the Shanghu Formation (e. g. mammal-defined boundary) lies about 2/3 the way up Chron C29r (Fig. 2A, B), which is comparable to the position of the Cretaceous-Paleogene (K/Pg) boundary in most other well-documented sections around the world (Clyde et al., 2010). The pollen-defined Cretaceous-Paleogene boundary, on the other hand, correlates to the lower part of Chron C29r or close to the top of Chron C30n, which is significantly older than the globally recognized K/Pg boundary (Erben et al., 1995; Clyde et al., 2010). In this paper, we accept the mammal-defined K/Pg boundary, because its stratigraphic position in Chron C29r corresponds closely with that of the current Cretaceous-Paleogene boundary in the geologic time scale (Gradstein et al., 2004).

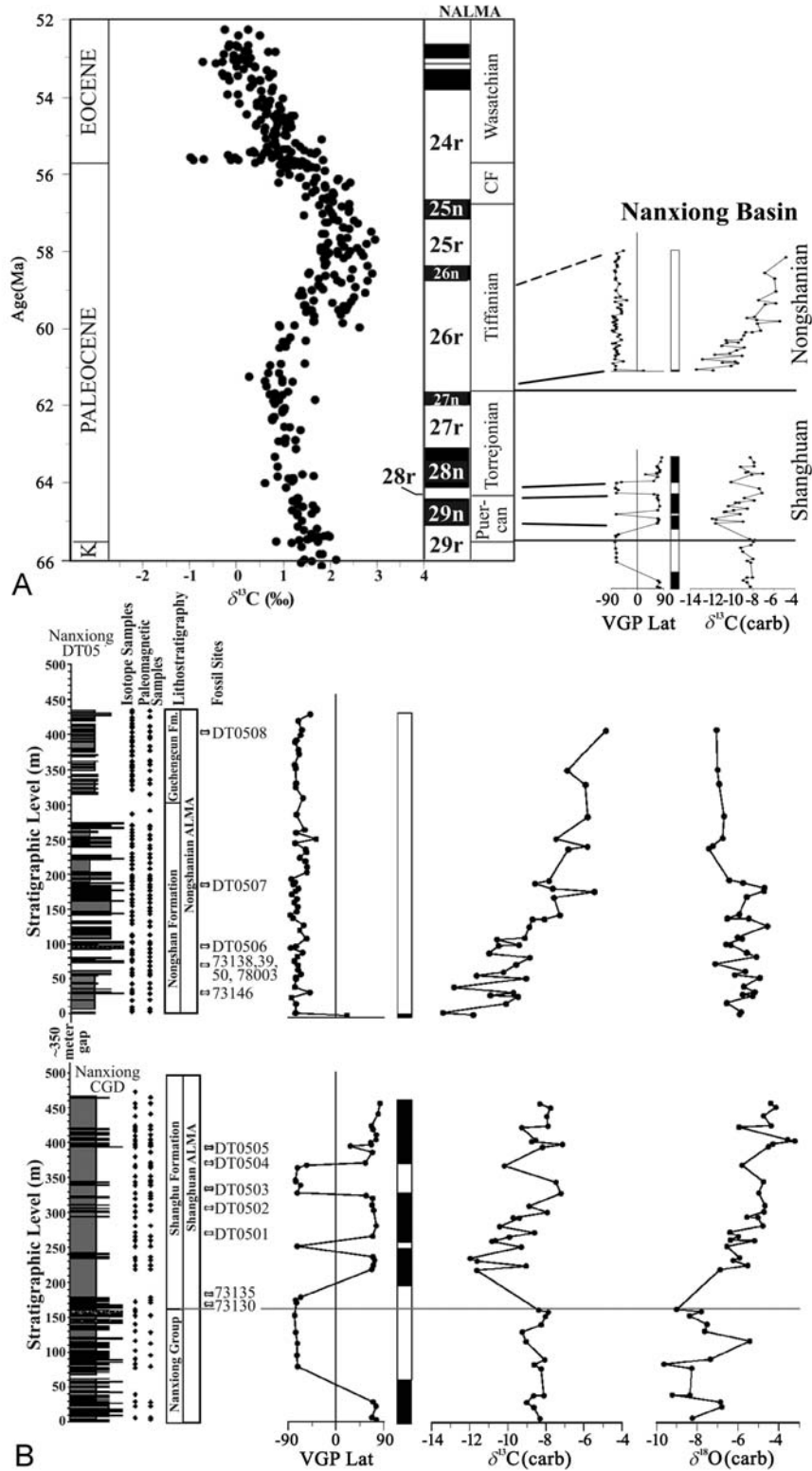


Fig. 2 Stratigraphic sections and paleomagnetic and isotopic results in Nanxiong Basin
 A. Correlation of the Nanxiong Basin stratigraphic record to the Geomagnetic Polarity Timescale. Composite carbon isotope record of deep-sea benthic foraminifera (from Zachos et al., 2001; ages recalibrated to Gradstein et al., 2004) is shown at left; B. Stratigraphic results from the Nanxiong Basin showing (from left to right) the lithological log, the stratigraphic position of isotope, paleomagnetic, and fossil samples; magnetostratigraphic results (black bars represent normal polarity and white bars represent reverse polarity); and stable-isotope results for the CGD and DT05 sections (Clyde et al., 2010)
 ALMA. Asian Land Mammal Age; VGP lat. Virtual Geomagnetic Pole latitude

The Shanghuan Land Mammal Age is marked by abrupt appearance of several “archaic” mammalian taxa. *Bemalambda*, a large herbivorous pantodont, first appeared in the early Shanghuan and became extinct by the end of the Shanghuan. It is widely distributed in all Shanghuan faunas, including the ones from the Shanghu (SH) (Fig. 1-1), Buxin (BX) (Fig. 1-2), Shizikou (SZ) (Fig. 1-3), Zaoshi (ZS) (Fig. 1-4), Wanghudun (WH) (Fig. 1-5), Gaoyugou (GY) (Fig. 1-10), Fangou (FG) (Fig. 1-11), and Juanling (JL) (Fig. 1-12) formations. These faunas group together into one of the major early Paleogene clusters (Fig. 3). The fauna from the Donghu Group, Xinzhou, Hubei (DH) (Fig. 1-9) was not included in the clustering analysis due to uncertainty of fossil identifications. The Shanghu and Wanghudun faunas are the richest among Shanghuan faunas (Li and Ting, 1983; Wang et al., 1998). Besides *Bemalambda*, they share more taxa than those of other faunas, including *Yantanglestes*, an early mesonychid, *Astigale*, an Asian endemic anagalid, and *Pappictidops*, an early carnivore. *Hypsilambda*, an advanced pantodont, occurred in the Zaoshi (Wang, 1975) and Buxin faunas (Wang and Zhang, 1997). The Shizikou, Juanling, and Gaoyugou faunas produce few taxa except *Bemalambda* (Tong et al., 1979; Wang et al., 1998; Tong and Wang, 1980). The Shanghuan is also characterized by the prevalence of Asian endemic forms, such as anagalids, simplicidentates, duplicidentates, and didymoconids. None of the genera in this age occur in North America or other continents. The appearance of taxa closely related to the ultimate ancestors of Rodentia and Lagomorpha, represented by the genera *Heomys* and *Mimotona* respectively, are unique for the Shanghuan. Paleomagnetic results (Clyde et al., 2010; Erben et al., 1995) indicate that the bottom of the Shanghu Formation corresponds to the upper part of Chron C29r in the Nanxiong Basin. Radiometric data from the basalt of the Donghu Group in the Xinzhou Basin, which is approximately equivalent to the upper part of the Shanghu Formation in the Nanxiong Basin, is dated to $\sim 61.63 \pm 0.92$ Ma, which correlates to Chron C27n (Tong et al., 2002; Wang et al., 1998). Our additional paleomagnetic information from both Nanxiong and

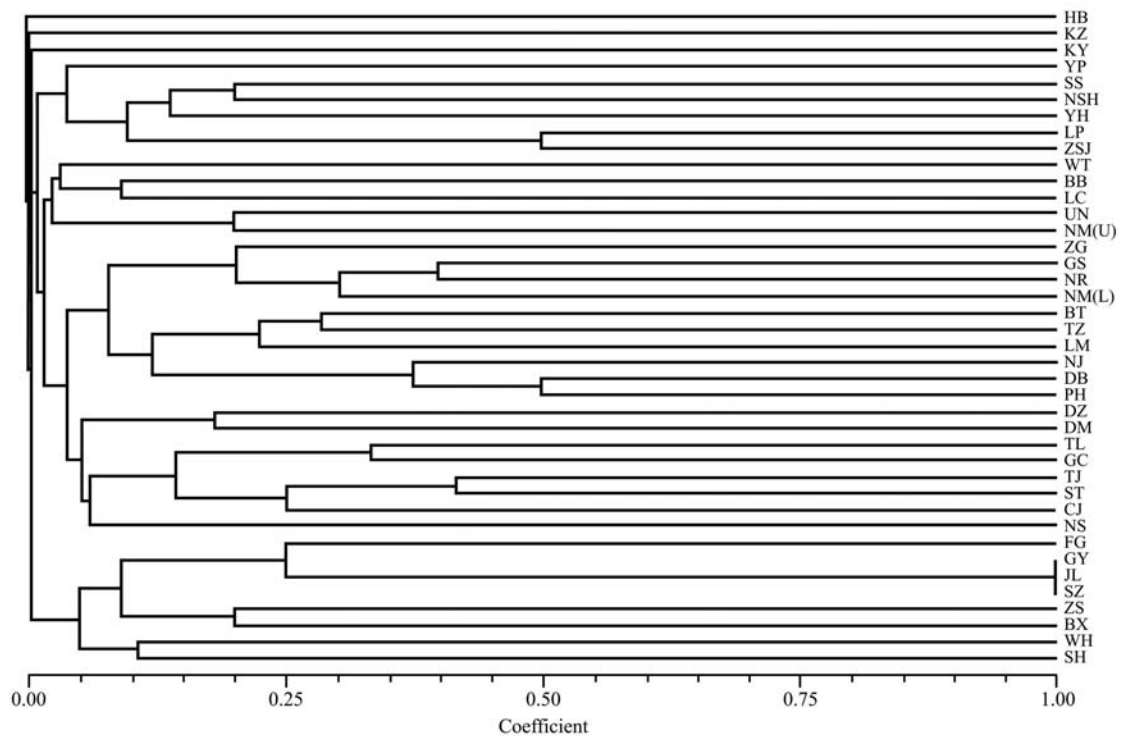


Fig. 3 Phenogram of 40 Asian Paleocene and early Eocene mammalian faunas based on UPGMA clustering analysis of Jaccard correlation coefficients on 216 genera (See text for additional explanation)

Chijiang basins are consistent with this as well in showing that the Shanghu and Shizikou formations, which are both characterized by Shanghuan faunas, span Chron C29r to C27n (Clyde et al., 2008; 2010). Based on both paleomagnetic and radiometric data, we suggest that the Shanghuan ALMA may be correlated to the Puercan and Torrejonian Land Mammal Ages (NALMA) in North America (Lofgren et al., 2004), and to the Danian in the marine record (Fig. 4).

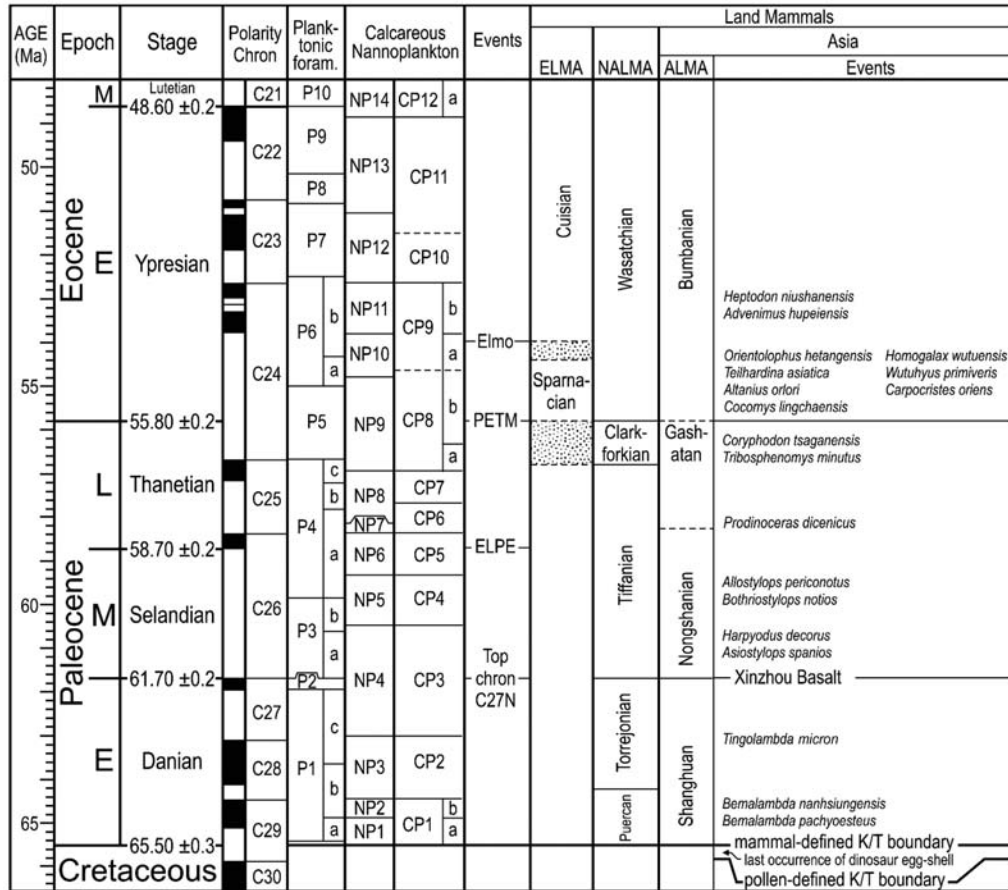


Fig. 4 Correlation of Asian Paleocene and early Eocene biostratigraphy (modified from Berggren and Aubry, 1998 and Gradstein et al., 2004)

3.2 Shanghuan-Nongshanian boundary and Nongshanian Land Mammal Age

The Shanghuan-Nongshanian boundary is best preserved in the Chijiang Basin, Jiangxi, China. The Chijiang Basin is located in the southern part of Jiangxi ($25^{\circ}23' \sim 25^{\circ}40' \text{N}$, $114^{\circ}20' \sim 114^{\circ}45' \text{E}$, Fig. 1-3). The first Paleocene mammalian fossils in the basin were discovered in 1972, including *Archaeoryctes notialis*, *Nanlinglambda chikiangensis*, and *Archaeolambda* sp. (Zheng et al., 1973), and a large number of fossils were found in the following year (Tong et al., 1976, 1979). The mammal-bearing strata in the basin are subdivided into three superimposed formations from the oldest to the youngest: the Shizikou, Chijiang, and Pinghu formations. The depositional relationship of the Pinghu Formation to the other units is not well constrained due to intervening overburden. The Shizikou Formation yields the typical Shanghuan taxon, *Bemalambda*, the Chijiang Formation contains a Nongshanian fauna, and the Pinghu Formation produces the Gashatan taxon, *Prodinoceras*.

Our recent paleomagnetic results across the boundary of the Shizikou and Chijiang formations show a long reversed polarity zone (zone B-) near the base of the composite section,

which is close to the Shanghuan-Nongshanian boundary (Fig. 5A, B). The long reversed polarity zone B- can be well correlated to Chron C26r, because Chron C26r is the longest interval of reversed polarity for the entire Cenozoic. The $\delta^{13}\text{C}_{\text{org}}$ results show high frequency variability superimposed on a secular increase in mean values of $\sim 1.5\%$ going up section (Clyde et al., 2008). This pattern is similar to that observed in marine $\delta^{13}\text{C}$ records, which show a secular increase of $\sim 1.5\%$ between ca. 57 Ma and the PETM (Zachos et al., 2001). The long paleomagnetic reversed polarity zone (zone B-) and the overall increase in average $\delta^{13}\text{C}$ of organic matter in the Chijiang Basin favor the correlation of the normal (zone A+) to reverse (zone B-) polarity transition near the base of the composite section to the Chron C27n to C26r reversal (Clyde et al., 2008). Combining the Xinzhou basalt radiometric date of $\sim 61.63 \pm 0.92$ Ma with the paleomagnetic and isotopic results in the Chijiang Basin, the Shanghuan-Nongshanian ALMA boundary seems to correlate to the Chron C27n-C26r reversal (Clyde et al., 2008). Recent results from the Nanxiong Basin also support this interpretation in showing that the Shanghuan correlates to the upper part of Chrons C29r through the upper part of C28n and the Nongshanian correlates to at least Chron C26r. In the marine record, the Danian-Selandian Stage boundary occurs at the top of Chron C27n (Gradstein et al., 2004). These data together suggest that the Shanghuan-Nongshanian boundary may correlate to the Tiffanian-Torrejonian NALMA boundary and the Danian-Selandian Stage boundary in the marine record (Clyde et al., 2008, 2010) (Fig. 4).

The Nongshanian Land Mammal Age is marked by the first appearance of a new order, Arctostylopida, represented by *Asiostylops spanios*, which occurs in the fauna of the Chijiang Formation (Chijiang Basin) and is the most primitive species in the order (Zheng, 1979). Arctostylopids soon diversified to include more advanced taxa, such as *Allostylops*, *Sinostylops*, and *Bothriostylops*. *Bothriostylops* occurred in the faunas from Nongshan (NS) (Fig. 1-1), Guchengcun (GC) (Fig. 1-1), Chijiang (CJ) (Fig. 1-3), Shuangtasi of Tongling (TL) (Fig. 1-6) and Xuancheng (ST) (Fig. 1-7) basins, and Tujinshan (TJ) (Fig. 1-8) formations, and an advanced pantodont, *Archaeolamda*, is commonly distributed in the faunas from Chijiang (CJ), Doumu (DM) (Fig. 1-5), Shuangtasi of Tongling (TL) and Xuancheng basins (ST), and Tujinshan (TJ) formations. These faunas group together closely in the cluster analysis (Fig. 3). However, the faunas from the Shuangtasi and Tujinshan formations differ from the typical Nongshanian faunas from the Nongshan, Chijiang, and Doumu formations in yielding more advanced mammalian taxa, especially the Gashatan taxa, such as *Palaeostylops iturus* and *Sarcodon? zhaii*, which indicate that the faunas from the Shuangtasi and Tujinshan formations may be younger than those from the Nongshan, Chijiang, and Doumu formations (Li and Ting, 1983; Ting, 1998; Tong et al., 1995; Wang et al., 1998). Huang et al. (1996) reported a middle or late Paleocene site from Xindoupo of Xijiadian, Hubei, which contains the fossil that is similar to *Prosarcodon* or *Sarcodon*. This site is not included in the cluster analysis, because the fossil from that site has not been published.

The appearance of the most primitive species of arctostylopids in the Nongshanian indicate that the arctostylopids may originate in Asia, and subsequently spread to North America (Beard, 1998; Cifelli et al., 1989; Zheng, 1979). Arctostylopids first appeared in North America during the Tiffanian and Clarkforkian, and were represented by an advanced form, *Arctostylops steini* (Rose, 1981). Taxa closely related to the ultimate ancestors of Perissodactyla and Artiodactyla, represented by *Radinskya yupingae* and *Ganungulatum xincunliense* respectively, also made their first appearance in the Nongshanian, which provide evidence that the Perissodactyla and Artiodactyla may have originated in Asia. The Nongshanian faunas are mainly composed of Asian endemic taxa; however, they show reduction of these forms compared to that of the Shanghuan. The Shanghuan-Nongshanian faunal turnover was likely affected by the environmental change during the traditionally defined Danian-Selandian transition and may possibly be related

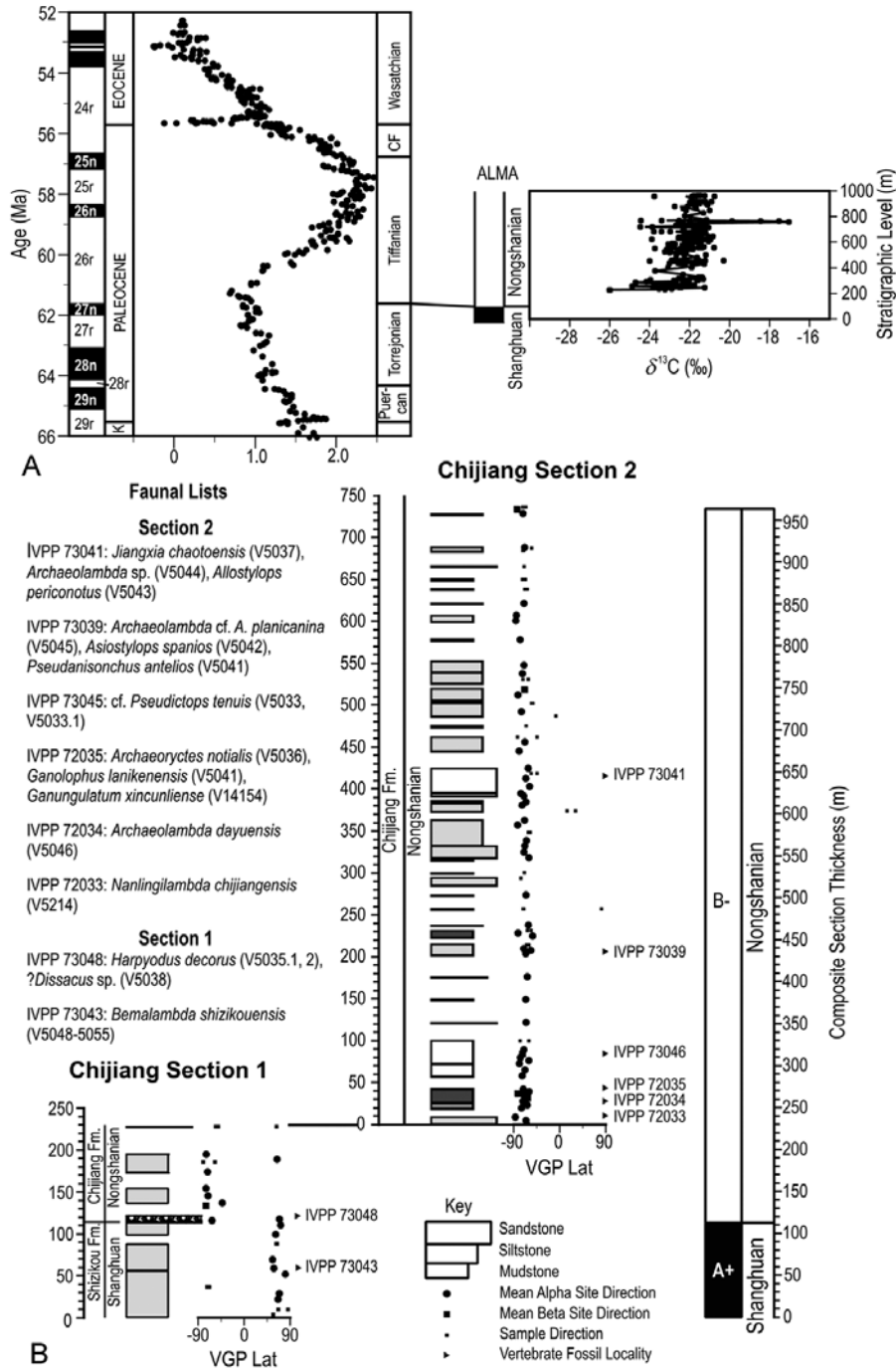


Fig. 5 Stratigraphic sections and paleomagnetic and isotopic results in Chijiang Basin

A. Carbon isotope values of organic carbon samples from Chijiang Section 2 correlated to the composite magnetostratigraphy from lower panel (black bar represents normal polarity and white bar represents reverse polarity). At left is the preferred correlation of the Chijiang Basin record to the North American Land Mammal Age framework (Lofgren et al., 2004), GPTS (Gradstein et al., 2004), and composite $\delta^{13}C$ record of benthic foraminifera from the deep sea (Zachos et al., 2001; ages recalibrated to Gradstein et al., 2004). Note the large negative excursion (PETM) at the Paleocene-Eocene boundary; B. Stratigraphy of Sections 1 and 2 from Chijiang Basin. Lithology is shown for the intervals of section that are exposed and VGP latitude (VGP lat) for alpha (large circles), beta sites (large squares), and samples from other sites (small squares) are plotted against stratigraphic level (meters). Sections are aligned according to correlations made in the field and trigonometric projection. Width of lithological beds represents grain size as shown in key whereas the shading represents color. Vertebrate fossil localities and stratigraphic position of key fossil localities are listed to right of lithological sections. Faunal lists for localities are given in top left of figure (Modified from Clyde et al., 2008)

to a marine geochemical event known as the “Top Chron C27n Event” (Westerhold et al., 2008). However, if the Shanghuan-Nongshanian faunal turnover is related to rapid climatic change, it likely represents an *in situ* evolutionary response rather than a climatically modulated dispersal event like the PETM since both the Shanghuan and Nongshanian faunas are composed primarily of Asian endemic forms.

3.3 The Nongshanian-Gashatan boundary and Gashatan Land Mammal Age

The Nongshanian-Gashatan boundary has not yet been constrained due to the lack of the superimposed strata that cross this boundary. The classic Gashatan fauna is preserved in the Nemegt Basin of Mongolia (Matthew and Granger, 1925; Matthew et al., 1929; Dashzevek, 1988; Szalay and McKenna, 1971) (Fig. 1-15), and also discovered in the Erlian Basin of Nei Mongol, China (43°00'N, 111°30'E) (Fig. 1-14). The Gashatan fauna in the Erlian Basin is found in the Nomogen Formation, which yields the typical Gashatan fossils, such as *Palaeostylops*, *Pseudictops*, *Prionessus*, *Hyracolestes*, *Sarcodon*, and *Eurymylus*, etc. as in the Nemegt Basin (Chow and Qi, 1978; Chow et al., 1976; Meng and McKenna, 1998; Meng et al., 1998). The paleomagnetic and isotopic results from the Erlian Basin indicate that Gashatan faunas occur within Chron C24r, and may have persisted close to the Paleocene-Eocene boundary and may be extended downward into Chron 25r or possibly C26n (Bowen et al., 2005) (Fig. 6). The most recent paleomagnetic data by Sun et al. (2009) indicate that the Nomogen Formation occurs between Chron C24r-C26r. However, the layer of the Nomogen Formation containing the Gashatan fauna in their section correlates to Chron C26n (Sun et al., 2009, fig. 3), and they also refer this fossil layer to the earliest late Paleocene. The new paleomagnetic and isotopic results from the Nanxiong Basin indicate that both Nongshan and Guchengcun formations may correlate to the upper part of Chron C26r (Fig. 2). Therefore, we suggest that the Nongshanian-Gashatan ALMA boundary must lie somewhere between the upper part of Chron C26r and C25n or possibly C26n, and may correlate within the Tiffanian NALMA (Bowen et al., 2005; Clyde et al., 2010).

The Gashatan Land Mammal Age is marked by the first appearance of a new order, Dinosauria, represented by *Prodinoceras*. The most primitive species, *Prodinoceras diconicus*, first appears in the Taizicun Formation (TZ) (Fig. 1-13) (Tong, 1978) and the genus soon becomes widely distributed in the faunas from Gashato (GS) (Fig. 1-16), lower part of Nomogen (NM(L)) (Fig. 1-14), Naran (NR) (Fig. 1-15) and Zhigden (ZG) (Fig. 1-15) of Naran Bulak, Dabu (DB) (Fig. 1-26), and Pinghu (PH) (Fig. 1-3) formations. These faunas are shown as a cluster, which is close to the Nongshanian faunas and distant from the Shanghuan faunas (Fig. 3). The faunas from the Gashato and the Naran and Zhigden members of Naran Bulak formations are most typical of the Gashatan age in sharing *Palaeostylops*, *Pseudictops*, *Prionessus*, *Gashatostylops*, and *Eurymylus*, and their “joint overlapping time ranges” are used to define the Gashatan age by Szalay and McKenna (1971:313). The appearance of Gashatan taxa, *Palaeostylops iturus* in the Shuangtasi Formation of the Xuancheng Basin and *Sarcodon? zhaii* in the Tujinshan Formation of Jiashan Basin, indicates that these faunas may correlate to the Gashatan. However, the faunas from the Shuangtasi and Tujinshan formations differ from the latter in lacking *Prodinoceras*, which occurs in the Gashatan faunas from Gashato, Naran and Zhigden members of Naran Bulak, lower Nomogen, Pinghu, Taizicun, and Dabu formations, and in having *Bathriostylops*, which does not occur in those Gashatan faunas, but in the Nongshanian faunas from the Nongshan, Guchengcun, and Chijiang formations.

The Gashatan is unique in recording the first appearance of the modern mammalian order Rodentia, represented by *Tribosphenomys minutus*. This discovery provides the best evidence that Rodentia originated in Asia and indicates the initiation of a transition from Paleocene “archaic” taxa to faunas dominated by “modern” taxonomic groups. A new ordinal record, the

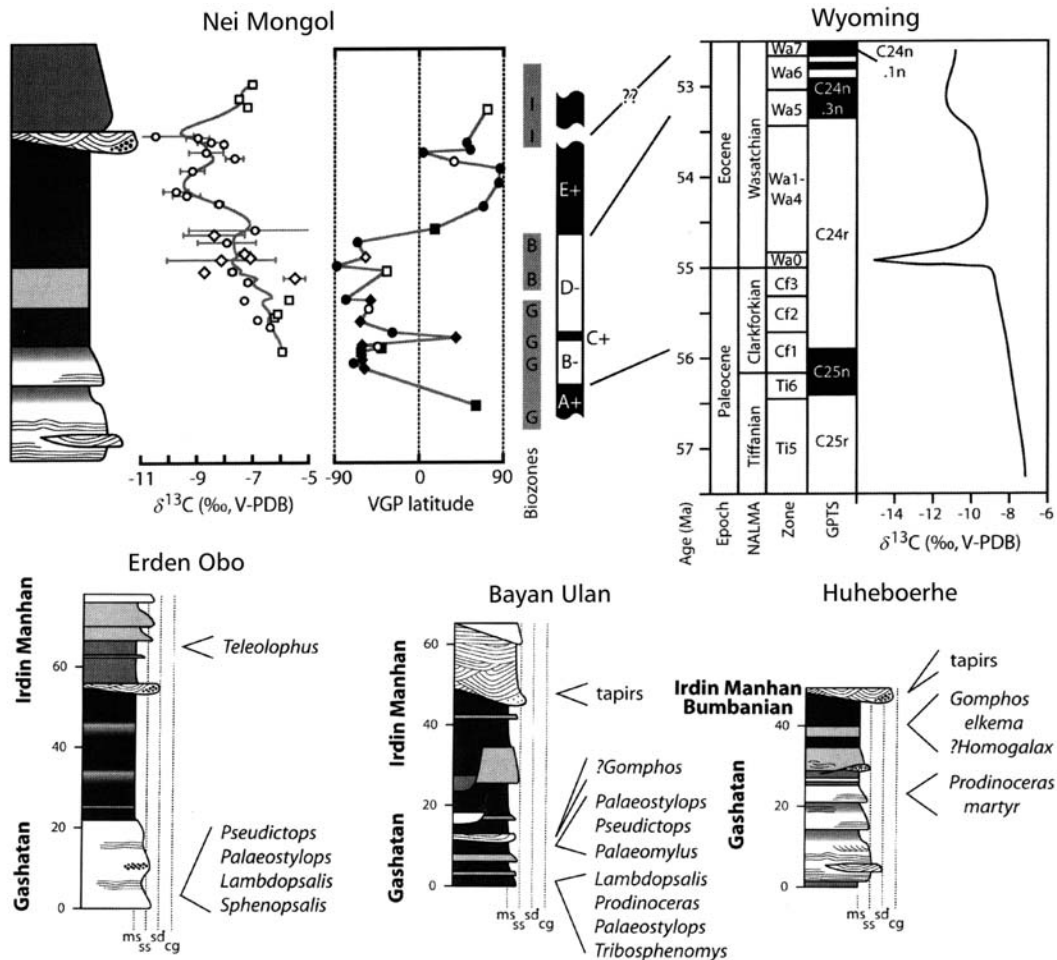


Fig. 6 Stratigraphic sections and paleomagnetic and isotopic results in Erlian Basin (from Bowen et al., 2005)

Multituberculata, also made its first Cenozoic appearance in Asia during the Gashatan, but is only known from the northern faunas. The Gashatan is characterized by shared occurrence of several taxa at the generic level with those of North American Clarkforkian, such as *Dissacus*, *Coryphodon*, *Viverravus*, *Pachyaena* (Rose, 1981), and by further reduction of Asian endemic forms. The appearance of the most primitive species of *Prodinoceras* in the Gashatan indicates that the dinoceratans most likely originated in Asia (Beard, 1998; Tong, 1978). The appearance of a primitive creodont, *Prolimnocyon chowi*, in the Gashatan indicates that creodonts may also have originated in Asia (Bowen et al., 2002; Meng et al., 1998; Ting et al., 2003). All of these first occurrences support the idea that Asia was a cradle of origination of many modern mammalian orders during the early Paleogene (Beard, 1998).

3.4 Paleocene-Eocene boundary and the Bumbanian Land Mammal Age

Asian Paleocene-Eocene boundary deposits are preserved in several basins, including the Nemegt of Mongolia (Fig. 1-28), and the Hengyang (Fig. 1-18) and Erlian (Fig. 1-27) basins of China. However, we have only found the transient carbon isotope excursion that marks the Paleocene-Eocene boundary in the Hengyang Basin at present (Bowen et al., 2002; Ting et al., 2003). The Hengyang Basin is located in the south-central part of Hunan Province, China (27°05'N, 112°57'E, Fig. 1-18). Young (1944) described the first Eocene mammal fossil, *Propachynolophus* (*Propalaeotherium*) *hengyangensis*, discovered in this basin. Li et al. (1979) later reported two mammal-bearing layers, the lower containing *Archaeolambda* sp., and

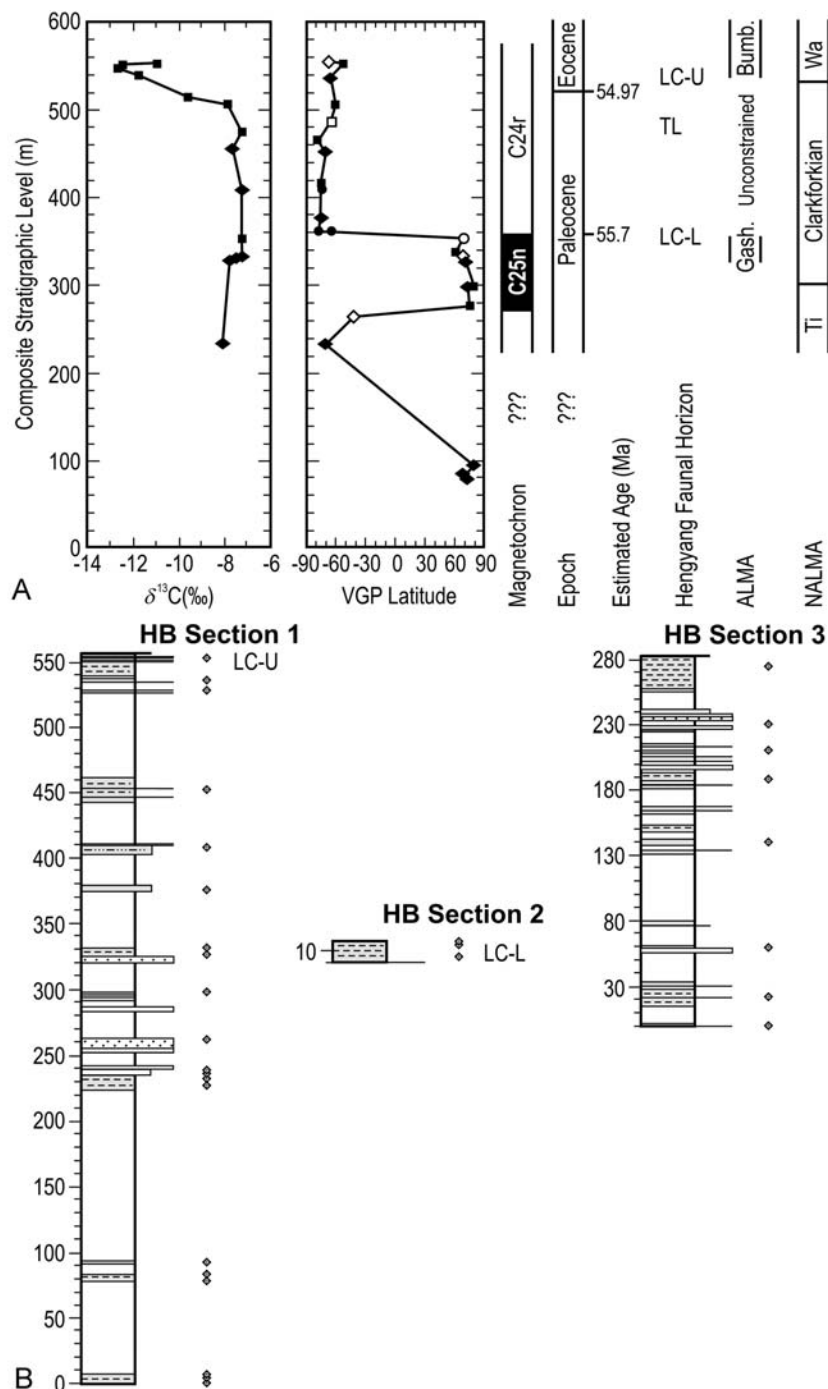


Fig. 7 Stratigraphy of the Limuping and Lingcha formations in the Hengyang Basin, Hunan Province

A. Stratigraphy and proposed correlations for the Hengyang Basin composite section. Carbon isotope and paleomagnetic results are classified by local section (diamonds = section 1, circles = section 2, squares = section 3) and were correlated among sections based on trigonometric projection and biostratigraphic data, supported by coincident patterns within the isotopic and magnetic data. Isotopic data show average values from 2 or more nodules within a single paleosol, and paleomagnetic data are shown as the average virtual geomagnetic pole (VGP) latitude for three samples (open symbols) or four or more samples (closed symbols). Estimated ages show for the C25n/C24r boundary and P-E boundary are based on Cande and Kent (1995) and Wing et al. (1999), respectively. Limuping and Lingcha faunal collection levels (LC-L and LC-U, respectively) constrain position of the Gashatan (Gash.)/Bumbanian (Bumb.) Asian Land Mammal Age (ALMA) boundary within the basin. TL, turtle fauna level, Ti, Tiffanian North American Land Mammal Age (NALMA), Wa, Wasatchian NALMA (from Bowen et al., 2002); B. Lithostratigraphy and sample distribution for paleomagnetic and isotopic stratigraphy of three local sections. Section levels are given in meters

the upper yielding an early Eocene fauna, including *Cocomys lingchaensis*, *Matutinia nitidulus*, *Hunanictis inexpectatus*, and *Asiocoryphodon* sp. Intensive studies of the strata and fossil collecting in this basin have been continued since then (Li and Ting, 1983; Ting, 1993, 1995; Ting and Li, 1984, 1987). The Hengyang strata that cross the Paleocene-Eocene boundary are between the Limuping Formation (lower Lingcha Formation of Bowen et al., 2002 and Ting et al., 2003; Tong et al., 2002) and Lingcha Formation (upper Lingcha Formation of Bowen et al., 2002 and Ting et al., 2003; Tong et al., 2002), and the latter is superimposed on the former. The paleomagnetic and isotopic results in the Hengyang Basin show two well-delineated magnetic polarity zones and a dramatic negative shift in paleosol carbonate $\delta^{13}\text{C}$ values within the upper reversed polarity zone (Fig. 7). The Paleocene-Eocene boundary is placed at 516 m in the composite section, the first level producing unusually low $\delta^{13}\text{C}$ values. The uppermost reversed polarity interval within the Hengyang composite section is correlated to Chron C24r, and the underlying normal polarity interval to Chron C25n (Bowen et al., 2002; Cande and Kent, 1995; Ting et al., 2003). The Lingcha fauna occurs between ~ 15 m above the Paleocene-Eocene boundary and the carbon isotope minimum at 548 m. The Lingcha fauna seems to correlate to the earliest Wasatchian (Wa0) on a scale of $\sim 10^4$ yr, and the Limuping fossils, found within meters of the Chron C25n/C24r reversal, can be correlated to the earliest subzone of the Clarkforkian NALMA (Bowen et al., 2002; Ting et al., 2003) (Fig. 4).

The Bumbanian Land Mammal Age is marked by abrupt synchronous first appearances of several modern mammalian orders, represented by *Orientalophus* and *Homogalax* (Perissodactyla), *Teilhardina* and *Altanius* (Primate), *Wutuhysus* (Artiodactyla), and by the last occurrences of the extinct mammalian order, Acreodi, represented by *Dissacus zengi* and *D. bohaiensis*, a mammalian taxon commonly distributed in the Paleocene deposits. The faunas from the Lingcha (LC) (Fig. 1-18), Wutu (WT) (Fig. 1-23), and Bumban Member of Naran Bulak formations (BB) (Fig. 1-28) share the occurrence of *Orientalophus* (*Homogalax*) and *Hapalodectes*, a small acreodan. They are closely clustered as a basal Bumbanian group, and are distant from the rest of Bumbanian faunas that produce *Heptodon*, an advanced perissodactyl. These more advanced Bumbanian faunas include those from the Niushan Formation of Wutu (NSH) (Fig. 1-24), Yuhuangding (YH) (Fig. 1-25), and the Shisanjianfang (SS) (Fig. 1-26) formations (Fig. 3). The Eocene faunas from Pakistan and India were not included in the analysis because of their distant geographic positions. The Bumbanian ALMA is characterized by sharing several taxa with those of the early Wasatchian NALMA, including (at the family level) Omomyidae (Primate), Coryphodontidae (Pantodonta), Hyaenodontidae (Creodonta), Viverravidae and Miacidae (Carnivora), Mesonychidae (Acreodi), Hyopsodontidae (Condylarthra), and (at genera level) *Teilhardina*, *Coryphodon*, *Hyopsodus*, *Homogalax*, and *Heptodon*. The extinct family Hyaenodontidae appeared first in the Gashatan ALMA (Meng et al., 1998) and then at the beginning of the Wasatchian NALMA, which indicates that Hyaenodontidae most likely spread to North America from Asia during Paleocene-Eocene transition. The transient carbon isotope excursion found in the Hengyang Basin precisely correlates the Asian Paleocene-Eocene boundary to the geological time scale, indicating that the Gashatan-Bumbanian faunal turnover is closely related to PETM global climate change, and records a major wave of migration between Asia and other continents.

4 Conclusion

Biostratigraphic, paleomagnetic, and isotopic results from the Nanxiong, Chijiang, Qianshan, Hengyang, and Erlian basins provide geochronologic constraints on Asian Paleocene and early Eocene strata. These independent chronologic data indicate that the base of the Shanghuan ALMA likely correlates with the K/T boundary, the Shanghuan-Nongshanian ALMA boundary

correlates closely with the traditional placement of the Danian-Selandian Stage boundary and Torrejonian-Tiffanian NALMA boundary, and the Gashatan-Bumbanian ALMA boundary correlates with the Paleocene-Eocene boundary (= PETM) and Clarkforkian-Wasatchian NALMA boundary. The Nongshanian-Gashatan ALMA boundary is poorly constrained at present but must occur between Chron C26n and C25r, and may also be related to a global climatic change.

A cluster analysis shows that the faunal assemblages from Kazakhstan and Kyrgyzstan are quite different from those of China and Mongolia at the generic level. Within East Asia, three major clusters of early Paleogene faunas were distinguished: the Shanghuan faunas, the Nongshanian and Gashatan faunas, and the Bumbanian faunas. The Shanghuan ALMA is marked by the abrupt appearance of several archaic mammal orders after the extinction of dinosaurs. The Nongshanian ALMA is marked by the first appearance of the order Arctostylopida, including the occurrence of the most primitive species, which indicates the possible origination of Arctostylopida in Asia. Both the Shanghuan and Nongshanian faunas are mainly composed of Asian endemic taxa. The Gashatan ALMA is marked by the first appearances of the order Dinocerata, including the most primitive species. The most primitive dinoceratan and a species of the modern order Rodentia appearing in the Gashatan indicate the origination of these taxa in Asia as well, and also mark the initiation of a transition from Paleocene "archaic" taxa to faunas dominated by "modern" taxonomic groups. The Bumbanian ALMA faunas are cosmopolitan. The modern mammalian orders, Primates, Perissodactyla, and Artidactyla, synchronously appeared at the beginning of the Bumbanian as in North American and Europe, and indicate a major mammalian exchange between Asia and other continents. These faunal turnovers are all closely related to the early Paleogene global climate changes best documented in deep sea records.

The evidence of the Gashatan and Bumbanian faunas in the Erlian Basin in this paper is based on the work in the year 2002. Very important progress and detail fossil and stratigraphic research in this basin have been made since then (see Wang et al., 2010).

Acknowledgements This paper is dedicated to the late Dr. Minchen Chow, the founder of the study of Paleogene mammals in China. His legacy and encouragement enlightened our research on Asian early Paleogene strata and fossil mammals. Our special thanks goes to the late Dr. Malcolm C. McKenna of American Museum of Natural History, who joined the Hengyang field work in 2000 and resulted in discovering the first temporally constrained Asian Paleocene-Eocene boundary. His advice and significant suggestions run throughout the research. The Hengyang trip was funded by National Geographic Society Grant 6528-99 to Ting (PI), Koch, and Clyde, and by the Major Basic Research Project of Ministry of Science and Technology, China (2006CB806400). The Chijiang trip (extended to include Nanxiong and Qianshan) was funded by National Geographic Society Grant 7329-02 to Ting (PI), Koch, and Clyde, NSF Grant EAR0540835 to Clyde (PI), NSF Grant EAR0120727 to Meng (PI) and Koch. This research project has also been supported by the Hubert Charitable Foundation. The colleagues who joined the field work include: Yuan Wang of IVPP and Mrs. Priscilla McKenna to the Hengyang, Shuhua Xie of IVPP to all basins, Wei Zhou of IVPP to Qianshan and Nanxiong, Huaquan Shou and Fuqiao Shi of IVPP to Erlian. Field work was also supported by the county government or museum offices of Hengdong, Chijiang, Qianshan, and Nanxiong. Dr. J. A. Schiebout of Louisiana State University (LSU) joined some of fossil research and provided the computer cluster analysis program. Dr. M. O. Woodburne of Department of Geology, Museum of Northern Arizona, critically read the manuscript and gave very important suggestions. Dr. A. Averianov of Zoological Institute, Russian Academy of Sciences provided the information on Kyrgyzstan fauna. Lorene Smith of LSU helped the SAHN computer program. Mary Eggart of LSU made all of figures. Kate Warren, Ben Ho, John Finarelli, Nadia Mariano, Graham Messe and Elena Crete of University of New Hampshire helped with paleomagnetic measurements. We

express our sincere thanks to all of them.

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Appendix 1 Asian Paleocene and early Eocene Mammalian Species List

Mammalian species in the Shanghuan ALMA (SH. Shanghu Fm., WH. Wanghudun Fm., ZS. Zhaoshi Fm., FG. Fangou Fm., SZ. Shizikou Fm., GY. Gaoyugou Fm., JL. Juanling Fm., BX. Buxin Group, DH. Donghu Group)

Anagalida

Anagalidae

Linnania lofoensis SH
L. qinlingensis FG
Huaiyangale chianshanensis WH
Huaiyangale sp. WH
Diacronus wanghuensis WH
Eosigale gujingensis WH
Qipania yui WH
Wanogale hodungensis WH

Anaptogale wanghoensis WH

Chianshanian gianghuaiensis WH

Stenanagale xiangensis ZS

Astigalidae

Astigale nanxiongensis SH

A. wanensis WH

Zhujegale lirenensis SH

Z. jintangensis SH

Pseudictopidae

Anictops tabiepedis WH

<i>A. wanghudunensis</i> WH	<i>B. pachyoesteus</i> SH, JL, FG
<i>Anictops</i> aff. <i>A. tabiepedis</i> WH	<i>B. crassa</i> SH
<i>Paranictops majuscula</i> WH	<i>Bemalambda</i> cf. <i>B. crassa</i> WH
<i>Paranictops</i> sp. WH	<i>B. shizikouensis</i> SZ
? <i>Paranictops</i> sp. WH	<i>B. zhoui</i> FG
<i>Cartictops canina</i> WH	<i>Bemalambda</i> sp. WH, SZ, GY
Simplicidentata	<i>Bemalambda</i> indet. WH
Eurymylidae	<i>Hypsilolambda chalingensis</i> ZS
<i>Heomys</i> sp. WH	<i>H. impensa</i> ZS
Duplicidentata	<i>Hypsilolambda</i> spp. ZS
Mimotodidae	? <i>Hypsilolambda</i> sp. BX
<i>Mimotona wana</i> WH	<i>Bemalambdidae</i> indet. ZS
<i>M. lii</i> WH	Archaeolambdidae
Condylarthra	<i>Tingolambda</i> (<i>Archaeolambda</i>) <i>micron</i> SH
Hyopsodontidae	Alcidedorbignidae gen. et sp. n. WH
<i>Yuodon protoselenoides</i> SH	Archaeolambdidae indet. SZ
<i>Palasiodon siurenensis</i> SH	Pastoralodontidae
Periptychidae	<i>Altilambda pactus</i> WH
? <i>Ectoconus</i> sp. SH	<i>A. tenuis</i> WH
?Phenacodontidae gen. et sp. nov. SH	<i>A. yujingensis</i> WH
Acreodi	Harpyodidae
Mesonychidae	<i>Harpyodus euros</i> WH
<i>Yantanglestes feiganensis</i> SH	Plethorodontidae
<i>Y. conexus</i> WH	<i>Plethorodon chienshanensis</i> WH
<i>Dissacusium shanghoensis</i> SH	Insectivora
<i>Hukoutherium ambigum</i> SH	Micropternodontidae
<i>H. shimenensis</i> FG	<i>Prosarcodon luonanensis</i> FG
<i>Dissacus rotundus</i> ZS	<i>Carnilestes palaeoasiaticus</i> SH
Mesonychidae indet. GY	<i>C. major</i> SH
Tillodontia	Didymoconidae
Esthonychidae	<i>Zeutherium niteles</i> WH
<i>Lofochaius brachyodus</i> SH	Carnivora
<i>Anchilestes impolitus</i> WH	Miacidae
<i>Meiostylodon zaoshiensis</i> ZS	<i>Pappictidops acies</i> SH
<i>Huananius youngi</i> SH	<i>P. obtusus</i> SH
Family indet.	<i>P. orientalis</i> WH
<i>Benaius qianshuiensis</i> WH	Order uncertain
?Tillodonta	<i>Obtusodon hanhuaensis</i> WH
<i>Dysnoetodon minuta</i> SH	<i>Decoredon anhuiensis</i> WH
Pantodonta	<i>Wania chowi</i> WH
<i>Bemalambdidae</i>	Fossil mammal DH
<i>Bemalambda nanhsiungensis</i> SH, ZS	

Mammalian species in the Nongshanian ALMA (NS. Nongshan Fm., CJ. Chijiang Fm., DM. Doumu Fm., DZ. Dazhang Fm., GC. Guchengcun Fm., HB. Bamiao, Hubei, XD. Xindoupo site)

?Edentata	Simplicidentata
Ernanodontidae	Eurymylidae
<i>Ernanodon antelios</i> NS	<i>Heomys orientalis</i> DM
Anagalida	<i>Hanomys malcolmi</i> HB
Anagalidae	Eurymyloidea indet. DM
<i>Hsiuannania tabiensis</i> DM	Duplicidentata
<i>H. minor</i> CJ	Mimotonidae
<i>Hsiuannania</i> sp. DM	<i>Mimotona wana</i> DM, DZ
cf. <i>Huaiyangale leura</i> NS	<i>M. robusta</i> DM
Pseudictopidae	Condylarthra
<i>Hartictops mirabilis</i> NS	Hyopsodontidae
<i>H. meilingensis</i> NS	Hyopsodontidae gen. et sp. indet. CJ
<i>Allictops inserrata</i> DM	Periptychidae
cf. <i>Pseudictops tenuis</i> CJ	<i>Pseudanisonchus antelios</i> CJ
Pseudictopidae indet. DZ	Acreodi

- Mesonychidae
Yantanglestes datangensis NS
Jiangxia chaotoensis CJ
 ?*Dissacus* sp. CJ
 ?*Pachyaena* sp. NS
- Tillodonta
 Esthonychidae
Interogale datangensis NS
Yuesthonyx tingae DZ
- Arctostylopida
 Arctostylopidae
Asiostylops spanios CJ
Allostylops periconotus CJ
Bothriostylops notios CJ
B. medius NS
B. progressus GC
Bothriostylops sp. CJ
Sinostylops promissus DM, DZ
- Pantodonta
 Archaeolambdidae
Archaeolambda dayuensis CJ
A. tabiensis DM
A. cf. A. planicanina CJ
Archaeolambda sp. CJ
Nanlingilambda chijiangensis CJ
N. datangensis NS
 Pastoralodontidae
Altilambda pactus NS
A. minor NS
Altilambda sp. NS
Altilambda sp. nov. DM
- Harpyodidae
Harpyodus decorus CJ
 Pantolambdodontidae
Dilambda zhuguikengensis NS
- Insectivora
 Micropternodontidae
Hyracolestes ermineus DM
 cf. *Prosarcodon* (or *Sarcodon*) sp. XD
 Insectivora indet. CJ
 Didymoconidae
Wanolestes lii DM
- Order uncertain
 Phenacolphidae
Minchenella grandis NS
Yuelophus validus NS
Ganolophus lanikenensis CJ
Radinskya yupingae NS
Petroleumur brevirostre NS
Obtusodon hanhuaensis DM
Archaeoryctes notialis CJ
 Phenacolphidae gen. et sp. n. NS
 ?Family
Ganungulatum xincunliense CJ
- Mammalian species in the Gashatan ALMA (NM (L)). Lower part of Nomogen Fm., GS. Mem. 1 of Khashat (Gashato) Fm., NR. Naran Mem. of Naran Bluk Fm., ZG. Zhigden Mem. of Naran Bulak Fm., TZ. Taizicun Fm., ST, TL. Shuangtasi Fm., TJ. Tujinshan Fm., BT. Bugin Mem. of Naran Bulak Fm., DB. Dabu Fm., PH. Pinghu Fm., LM. Limuping Fm., KZ. Tashkentskie Chuli Area, Dzhilga 1a locality)
- Multituberculata
 Taeniolabidae
Prionessus lucifer NR, GS, NM (L)
Prionessus cf. *P. lucifer* NM (L)
Prionessus sp. NR, NM (L)
Lambdopsalis bulla NM (L)
Sphenopsalis nobilis NM (L), GS
Sphenopsalis sp. NM (L)
 Multituberculata indet. TZ
 Neoplagiulacidae
Mesodmops tenuis NM (L)
- ?Edentata
 Ernanodontidae
Ernanodon sp. ZG
- Anagalida
 Anagalidae
Hsiuannania maguensis ST, TJ
Hsiuannania sp. ST
Khashanagale zofiae GS
 ?*Khashanagale* sp. GS
 Pseudictopidae
Pseudictops lophiodon NR, GS, NM (L)
P. chaii TZ
Pseudictops sp. NM (L)
 Astigalidae
 Astigalidae gen. et sp. indet. NM (L)
- Simplicidentata
 Eurymylidae
Khaychina elongata BT, NR
 ?*K. elongata* NM (L)
Eomylys borealis NM (L)
E. bayanulanensis NM (L)
E. zhigdenensis ZG, NR, GS
Eurymylys laticeps NR, GS
Amar aleator ZG
Zagmys insolitus BT
 ?Eurymylidae indet. TZ
- Duplicidentata
 Mimotonidae
Mimotona sp. TJ
- Acreodi
 Mesonychidae
Dissacus indigenus NR
D. magushanensis ST
Dissacus sp. GS
D. serratus NM (L)
Pachyaena nemegetica NR
Pachyaena sp. NM (L)
Sinonyx jiashanensis TJ
 Mesonychidae indet. TZ
- Creodonta
 Oxyaenidae
Oxyaena sp. NR
 Hyaenodontidae
Prolimnocyon chowi NM (L)
 ?Creodonta indet. NM (L)

- Arctostylopida
 Arctostylopidae
Gashatostylops macrodon ZG, NR, GS, NM (L)
Palaeostylops iturus NM (L), GS, NR, ZG, ST
Palaeostylops sp. NM (L)
Arctostylops sp. ZG
Bothriostylops progressus ST, TJ, TL
Wanostylops youngi ST
W. promissus TJ
- Pantodonta
 Archaeolambdidae
Archaeolambda planicanina ZG, NR
 cf. *A. planicanina* TZ, LM
A. trofimovi BT
Archaeolambda sp. TJ
A. yangtzeensis ST
 cf. *A. yangtzeensis* TL
Guichilambda zhaili TL
- Pastoralodontidae
Pastoralodon lacustris NM (L)
P. haliutensis NM (L)
Convallisodon convexus NM (L)
- Pantolambdodontidae
Pantolambdodon lophiodon NM (L)
Dilambda speciosa TZ
- Harpyodidae
Harpyodus progressus TJ, ST
- Coryphodontidae
Coryphodon tsaganensis NR
C. dabuensis DB
- Dinocerata
 Prodinoceratidae
Prodinoceras martyr NR, GS, ZG
P. dionicus TZ
P. turfanensis TZ
P. primigenus TZ
P. simplum TZ
P. lacustris (australis) PH
P. xinjiangensis DB, NM (L)
P. efremovi NM (L)
Prodinoceras sp. BT
- Insectivora
 Micropternodontidae
Sarcodon pygmaeus GS
S. minor NM (L)
 ?*S. pygmaeus* NM (L)
S. ? zhaili TJ
Hyracolestes ermineus GS, ZG
Hyracolestes cf. *H. ermineus* NM (L)
- Mammalian species in the Bumbanian ALMA (WT. Wutu Fm., BB. Bumban Mem. of Naran Bulak Fm., KY. Alay Beds, LC. Lingcha Fm., YH. Yuhuangding Fm., SS. Shisanjianfang Fm., NM (U). Upper Nomogen Fm., NJ. Ningjiashan Mem. of Xinyu Group, LP. Leipi beds, ZSJ. Zhangshanji Fm., NSH. Niushan Fm., YP. Yuping Fm., UN. Mem. II and III of Khashat (Gashato) Fm., AT. Aguyt Mem. of Naran Bulak Fm., ZHG. Zhylga 1b)
- Multituberculata
 Neoplagiaucidae
Mesodmops dawsonae WT
- Pholidota
 Palaeonodontidae
Auroratherium sinense WT
- Anagalida
 cf. *Sinopa* sp. NR
- Nyctitheriidae
Bayanulanius tenuis NM (L)
Asionyctia guoi NM (L)
Bumbanius ningi NM (L)
Jarveia erronea ZG
J. minuscula KZ
Voltaia minuta KZ
- Nyctitheriidae sp. NM (L)
 Paleoryctoidea gen. et sp. n.
 (specimen V 11137) NM (L)
- Leptictidae
Praolestes nanus GS, ZG
P. maximus ZG
 ?Leptictidae gen. et sp. n. NM (L)
- Geolabididae
Gobigeolabis verigranum ZG
- Palaeoryctidae
Pinoryctes collector ZG
- Pantolestidae
Zhigdenia nemegetica ZG
- Cimolestidae
Tsaganium ambiguous NM (L)
- Didymoconidae
Archaeoryctes euryalis ZG
- Carnivora
 Viverravidae
 cf. *Viverravus* sp. NM (L)
- Primate
 Carpolestidae (Plesiadapiformes)
Subengius mengi NM (L)
- Rodentia
 ?Alagomyidae
Tribosphenomys minutus NM (L), ZG
T. secundus ZG
Tribosphenomys cf. *T. secundus* NM (L)
Neimengomys qii NM (L)
 ?Rodentia indet. NM (L)
- ?Perissodactyla
 Family indet. V 11149. 1–6, NM (L)
- Order uncertain
 Phenacolphidae
Tianshanilophus subashiensis TZ
T. lianmuqinensis TZ
T. shengjinkouensis TZ
Phenacolphus fallax GS
- ?Family
Wanotherium xuanchengensis ST
- Psudictopidae
Suyinia changleensis WT
- Astigalidae
Yupingale weifangensis WT
- Simplicidentata
 Eurymylidae
Zagmys insolitus BB

- Matutinia nitidulus* LC
Rhombomylus laianensis ZSJ
R. turpanensis SS
R. cf. R. turpanensis BB, LP
Rhombomylus sp. YH
Eomylus zhigdensis BB
Hannanomys lini LP
Decipomyidae
Decipomys mongoliensis BB
Duplicidentata
Mimotonidae
Gomphos elkema BB, UN, AT, NM (U)
Gomphos sp. NM (U)
Anatolmylus rozhdstvenskii KY
Aktashmys montealbus KY
Condylarthra
Hyopsodontidae
Hyopsodus orientalis BB
H. fangxianensis YP
Hyopsodus sp. SS
Asiohyopsodus confuciusi WT
Midiagnus gracilis BB
Phenacodontidae
Lophocion asiaticus WT
Acreodi
Mesonychidae
Dissacus zengi LC
D. bohaisensis WT
Dissacus sp. NM (U)
Mesonychidae indet. KY
Hapalodectidae
Hapalodectes hetangensis LC
H. huanghaiensis WT
Hapalodectes sp. BB
Tillodonta
Esthonychidae
Paresthyonx orientalis WT
Yuesthonychidae
Yuesthyonx sp. WT
Creodonta
Oxyaenidae
Oxyaena? sp. WT
Anthracoxyaena palustris WT
Hyaenodontidae
Preonictis youngi WT
Neoparapterodon n. sp. KY
Gen. et sp. n. KY
creodont NM (U)
Arctostylopida
Arctostylopidae
Anatolostylops dubius SS
A. zhaii NM (U)
Arctostylops sp. BB
Migrostylops roboreus WT
M. rosella WT
Pantodonta
Archaeolambdidae
Archaeolambda sp. n. BB
?Archaeolambdidae
Celaenolambda wangzhaoi WT
Coryphodontidae
Heterocoryphodon flerowi YH
? *H. yuntongi* WT
Wutucoryphodon xianwui WT
Coryphodon nинchiashanensis NJ
Coryphodon sp. SS
Asiocoryphodon conicus YH
A. lophodontus YH
Asiocoryphodon sp. LC
Menteodon cf. M. youngi YH
Dinocerata
Prodinoceratidae
Prodinoceras sinyuensis NJ
P. efremove BB
Gobiatherium sp. YH
? *Mongolotherium* sp. WT
Insectivora
Erinaceidae
Luchenus erinaceanus WT
Protogalericius averianovi KY
?Amphilemuridae
Hylomysoides qiensis WT
Qilulestesschieboutae WT
Nyctitheriidae
Bumbanius rarus BB
Oedolius perexiguus BB
Edzenius lus BB
Eosoricodon terrigema BB
Nyctitheriidae gen. indet. BB
Lipotyphla indet. BB
?Nyctitheriidae
Talpilestes asiatica WT
Leptictidae
Asioictops mckennai WT
Scileptictis simplus WT
? *S. stenotalus* WT
Cimolestidae
Naranius infrequens BB
cf. *Naranius* sp. LC
Tsaganianus ambiguus BB
Bagalestes trofimovi BB
Paleoryctidae
Nuryctes alayensis KY
Palaeoryctidae gen. et sp. indet. KY
Pantolestidae
Pantolestidae gen. indet. BB
Micropetnodontidae
Hsiangolestes youngi LC
cf. *Hyracolestes* sp. BB
Prosarcodon maturus BB
Sarcodon (Metasarcodon) udovichenkoi KY
Changlelestidae
Changlelestes dissetiformis WT
Plesiosoricidae
Ordolestes ordinates BB
Didymoconidae
Hunanictis inexpectatus LC
Lipotyphla
Gen. et sp. indet. KY
Insectivora gen. et sp. n. LC
Carnivora
Miacidae
Xinyuictis tenuis NJ
Zodiocyon zetesios WT

- Viverravidae
Variviverra vegetates WT
- Lagomorpha
 Strenulagidae
Gobiolagus hekkeri KY
 Mytonolagidae
Valerilagus reshetovi KY
 Family uncertain
Arnebolagus leporinus BB
 lagomorph NM (U)
- Rodentia
 Alagomyidae
Alagomys inopinatus BB
A. oriensis WT
 Ivanantoniidae
Ivanantonia efremovi BB
 ?Yuomyidae
Bandaomys zhonghuaensis WT
 Paramyidae
Taishanomys changlensis WT
T. parvulus WT
 ?*Acritoparamys wutui* WT
 ?*Acritoparamys* sp. WT
 Cocomyidae
Cocomys lingchaensis LC
Sharomys singularis BB
S. parvus BB
Kharomys mirandus BB
K. gracilis BB
Tsagamys subitus BB
 cf. *Tsagamys* sp. LC
Ulanomys mirificus BB
Advenimus hupeiensis YH
Advenimus cf. *A. burkei* KY
Adolomys ameristus BB
Tsagankhushumys deriphatus BB
Bumbanomys edestus BB
 ?*Esesempomys centralasiae* BB
Hohomys lii YH
 Cocomyidae gen. et sp. indet. YH
 Orogomyidae
Orogomys obscurus BB
 Chapattimyidae
Petrokozlovia cf. *P. notos* KY
Saykanomys cf. *S. bohlini* KY
Khodzhentia vinogradovi KY
 Tamquammyidae
Alaymys ctenodactylus KY
 ?*Adolomys* sp. KY
 Ctenodactyloidea indet. KY
 Rodentia indet. WT
 rodents NM (U)
- Primate
 Omomyidae
Altanius orlovi BB
Teilhardina asiatica LC
Baataromomys ulaanus UM(U)
 Carpolestidae (Plesiadapiformes)
Chronolestes simul WT
- Carpocristes oriens* WT
- Plesiadapidae
Asioplesiadapis youngi WT
- Paromomyidae
 cf. *Ignacius* sp. nov. WT
- ?Paromomyidae
Dianomomys ambiguus WT
- ?Micromomyidae gen. et sp. nov. WT
- Proboscidea?
 Anthracobunidae
Pilgrimella sp. n. KY
- Perissodactyla
 ?Isectolophidae
Orientolophus hengdongensis LC
 ?*O. namadicus* BB
 ?*O. gabunia* BB
Homogalax wutuensis WT
Homogalax sp. WT
 ?*Homogalax* sp. WT
Chowliia laoshanensis WT
Chowliia cf. *C. laoshanensis* WT
- Lophialetidae
Eoteles tianshanicus KY
 ?*Lophialetes* sp. KY
- ?Lophialetidae
Ampholophys luensis WT
- Heleatidae
Heptodon niushanensis NSH
H. tianshanensis SS
 cf. *Heptodon* sp. YH
 ?*Heptodon* sp. NJ
- Depertellidae
Teleolophus medius KY
- Hyracodontidae
Forstercooperia sp. KY
- Eomoropidae
Pappomoropus taishanensis WT
Danjiangia pingi YH
- Family uncertain
Propachynolophus hengyangensis LC
 ?*Eomorops* sp. or ?cf. *Propachynolophus* sp. KY
- Rhodopagidae
Pataecops minutissimus KY
 ?*Pataecops parvus* NM (U)
- Amynodontidae
Sharamynodon kirghisiensis KY
- Artiodactyla
 Dichobunidae
Diacodexis sp. KY
Diacodexis indet. KY
Tsaganohyus pecus BB
Eolantianius russelli KY
 ?*E. russelli* gen. et sp. n. KY
- Familyincertae sedis
Wutuhyus primiveris WT
- Artiodactyls ZHG
 ?artiodactyl NM (U)
- Order incertae sedis
Olbitherium millenarianicus WT

Appendix 2 Asian Paleocene-E. Eocene Faunal List for cluster analysis

Shanghuan Land Mammal Age

SH (Shanghu Fm., Nanxiong Basin, Guangdong)

Carnilestes palaeoasiaticus, *C. major*, *Dissacusium shanghoensis*, *Yuodon protoselenoides*, *Palasiodon siurenensis*, *Bemalambda nanhsiungensis*, *B. pachyoesteus*, *B. crassa*, ?*Ectoconus* sp., *Hukoutherium ambigum*, *Linnania lofoensis*, *Yantanglestes feiganensis*, *Lofochaius brachyodus*, *Tingolambda* (*Archaeolambda*) *micron*, *Zhujegale lirenensis*, *Z. jintangensis*, *Astigale nanxiongensis*, *Dysnoetodon minuta*, *Pappictidops acies*, *P. obtusus*, *Huananius youngi*, ?*Phenacodontidae* gen. et sp. n.

WH (Wanghudun Fm., Qianshan Basin, Anhui)

Bemalambda sp., *Bemalambda* cf. *B. crassa*, *Astigale wanensis*, *Yantanglestes conexus*, *Wanogale hodungensis*, *Anaptogale wanghoensis*, *Chianshanian gianghuaiensis*, *Cartictops canina*, *Anictops tabiepedis*, *A. wanghudunensis*, *Anictops* aff. *A. tabiepedis*, *Paranictops majuscula*, ?*Paranictops* sp., *Anchilestes impolitus*, *Zeutherium niteles*, *Eosigale gujingensis*, *Huaiyangale chianshanensis*, *Huaiyangale* sp., *Qipania yui*, *Diacronus wanghuensis*, *Mimotona wana*, *M. lii*, *Pappictidops orientalis*, *Harpyodus euros*, *Altilambda pactus*, *A. yujingensis*, *A. tenuis*, *Heomys* sp., *Decoredon anhuiensis*, *Obtusodon hanhuaensis*, *Wania chowi*, *Benaius qianshuiensis*, *Plethorodon chianshanensis*, *Bemalambdidae* indet., ?*Alcidedorbignyidae* gen. et sp. n.

ZS (Zaoshi Fm., Chaling Basin, Hunan)

Stenanagale xiangensis, *Dissacus rotundus*, *Meiostylodon zaoshiensis*, *Bemalambda nanhsiungensis*, *Hypsilolambda chalingensis*, *H. impensa*, *Hypsilolambda* spp., *Bemalambdidae* indet.

FG (Fangou Fm., Shimen Basin, Shaanxi)

Prosarcodon luonanensis, *Linnania qinlingensis*, *Bemalambda zhoui*, *Bemalambda* cf. *B. pachyoesteus*, *Hukoutherium shimensis*

SZ (Shizikou Fm., Chijiang Basin, Jiangxi)

Bemalambda shizikouensis, *Bemalambda* sp., *Archaeolambdidae* indet.

GY (Gaoyugou Fm., Tantuo Basin, Henan)

Bemalambda sp., *Mesonychidae* indet.

JL (Juanling Fm., Shanyang Basin, Shaanxi)

Bemalambda cf. *B. pachyoesteus*

BX (Fm. I of Buxin Group, Sanshui Basin, Guangdong)

?*Hypsilolambda* sp.

DH (Donghu Group, Xinzhou, Hubei)

Fossil mammal

Nongshanian Land Mammal Age

NS (Nongshan Fm., Nanxiong Basin, Guangdong)

Dilambda zhuguikengensis, ?*Pachyaena* sp., cf. *Huaiyangale leura*, *Haltictops mirabilis*, *H. meilingensis*, *Interogale datangensis*, *Yantanglestes datangensis*, *Altilambda pactus*, *A. minor*, *Altilambda* sp., *Nanlingilambda datangensis*, *Nanlingilambda* sp., *Ernanodon antelios*, *Petrolemu brevirostre*, *Minchenella grandis*, *Yuelophus validus*, *Radinskya yupingae*, *Bothriostylops medius*, *Phenacolophidae* gen. et sp. n.

CJ (Chijiang Fm., Chijiang Basin, Jiangxi)

Archaeoryctes notialis, *Hsiuannania minor*, cf. *Pseudictops tenuis*, ?*Dissacus* sp., *Pseudanisonchus antelios*, *Archaeolambda dayuensis*, *Archaeolambda* cf. *A. planicanina*, *Archaeolambda* sp., *Nanlingilambda chijiangensis*, *Harpyodus decorus*, *Asiostylops spanios*, *Bothriostylops notios*, *Bothriostylops* sp., *Ganolophus lanikenensis*, *Allostylops periconotus*, *Jiangxia chaotoensis*, *Ganungulatum xincunliense*, *Hyopsodontidae* gen. et sp. indet., *Insectivora* indet.

DM (Doumu Fm., Qianshan Basin, Anhui)

Hsiuannania tabiensis, *Hsiuannania* sp., *Allictops inserrata*, *Mimotona robusta*, *M. wana*, *Altilambda* sp. n., *Obtusodon hanhuaensis*, *Hyracolestes ermineus*, *Heomys orientalis*, *Archaeolambda tabiensis*, *Wanolestes lii*, *Sinostylops promissus*, *Eurymyloidea* indet.

DZ (Dazhang Fm., Tantou Basin, Henan)

Yuesthonyx tingae, *Mimotona wana*, *Sinostylops promissus*, *Pseudictopidae* indet.

GC (Guchengcun Formation, Nanxiong Basin, Guangdong)

Bothriostylops progressus

HB (*Hanomys*-bearing beds, Danjiangkou city, Hubei)

Hanomys malcolmi

XD (Xindoupo fossils site, Xindoupo Village, Xijiadian, Hubei)

cf. *Prosarcodon* (or *Sarcodon*) sp.

Gashatan Land Mammal Age

NM (L) (Lower part of Nomogen Fm., Erlian Basin, Nei Mongol)

Lambdopsalis bulla, *Prionessus lucifer*, *Prionessus* cf. *P. lucifer*, *Prionessus* sp., *Sphenopsalis nobilis*, *Sphenopsalis* sp., *Sarcodon minor*, ?*Sarcodon pygmaeus*, *Hyracolestes* cf. *H. ermineus*, *Bayanulanius tenuis*, *Pseudictops lophiodon*, *Pseudictops* sp., *Eomylys borealis*, *E. bayanulanensis*, ?*Khaychina elongata*, *Tribosphenomys minutus*, *Tribosphenomys* cf. *T. secundus*

dus, *Neimengomys qii*, *Prolimnocyon chowi*, cf. *Viverravus* sp., *Pachyaena* sp., *Dissacus serratus*, *Pastoralodon lacustris*, *P. haliutensis*, *Convallisodon convexus*, *Prodinoceras efremovi*, *P. xinjiangensis*, *Palaeostylops iturus*, *Palaeostylops* sp., *Gashatostylops macrodon*, *Pantolambdodon lophiodon*, *Palaeomyilus lii*, *Palaeomyilus* sp., *Asionyctia guoi*, *Mesodmops tenuis*, *Bumbanius ningi*, *Tsaganius ambiguous*, *Subengius mengi*, ?Leptictidae new genus and species, *Palaeoryctoidea* gen. et sp. indet., *Astigalidae* gen. et sp. indet., *Perissodactyla* (Family indeterminate), *Nyctitheriidae* sp., *Rodentia* indet., ?*Creodonta* indet.

GS (Member I of Khashat (Gashato) Fm., Ulan Nur Basin, Mongolia)

Sarcodon pygmaeus, *Hyracolestes ermineus*, *Praolestes nanus*, *Khashanagale zofiae*, ?*Khashanagale* unnamed n. sp., *Pseudictops lophiodon*, *Eurymylus laticeps*, *Eomyilus zhigdenensis*, *Prodinoceras martyr*, *Palaeostylops iturus*, *Gashatostylops macrodon*, *Prionessus lucifer*, *Sphenopsalis nobilis*, *Phenacolophus fallax*, ?*Dissacus* sp. n.

NR (Naran Mem. of Naran Bulak Fm., Nemegt Basin, Mongolia)

Prionessus lucifer, *Prionessus* sp., cf. *Sinopa* sp., *Eurymylus laticeps*, *Eomyilus zhigdenensis*, *Oxyaena* sp., *Archaeolambda planicanina*, *Coryphodon tsaganensis*, *Prodinoceras martyr*, *Gashatostylops macrodon*, *Pseudictops lophiodon*, *Dissacus indigenus*, *Pachyaena nemegetica*, *Palaeostylops iturus*, *Khaychina elongata*

ZG (Zhigden Mem. of Naran Bulak Fm., Nemegt Basin, Mongolia)

Ernanodon sp., *Amar eleator*, *Archaeolambda planicanina*, *Prodinoceras martyr*, *Gashatostylops macrodon*, *Palaeostylops iturus*, *Arctostylops* sp., *Eomyilus zhigdenensis*, *Jarveia erronea*, *Praolestes maximus*, *P. nanus*, *Tribosphenomys secundus*, *Hyracolestes ermineus*, *Gobigeolabis verigranum*, *Archaeoryctes euryalis*, *Pinoryctes collector*, *Zhigdenia nemegetica*

TZ (Taizicun Fm., Turfan Basin, Xinjiang)

Pseudictops chaili, *Archaeolambda* cf. *A. planicanina*, *Dilambda speciosa*, *Tienshanilophus subashiensis*, *T. lianmuqinensis*, *T. shengjinkouensis*, *T. turfanensis*, *Prodinoceras diconicus*, *P. primigenus*, *P. simplum*, *Multituberculata* indet., *Eurymyidae* gen. et sp. indet., *Mesonychidae* indet.

ST (Shuangtasi Fm., Xuancheng Basin, Anhui)

Hsiuannania maguensis, *Hsiuannania* sp., *Dissacus magushanensis*, *Bothriostylops progressus*, *Archaeolambda yangtzeensis*, *Archaeolambda* cf. *A. yangtzeensis*, *Wanotherium xuanchengensis*, *Harpyodus progressus*, *Palaeostylops iturus*, *Wanostylops youngi*

TL (Shuangtasi Fm., Tongling Basin, Anhui)

Bothriostylops progressus, *Archaeolambda* cf. *A. yangtzeensis*, *Guichilambda zhaili*

TJ (Tujinshan Fm., Jiashan Basin, Anhui)

Sinonyx jiashanensis, *Sinomyilus zhaili*, *Sarcodon zhaili*, *Wanostylops promissus*, *Mimotona* sp., *Archaeolambda* sp., *Hsiuannania maguensis*, *Harpyodus progressus*, *Bothriostylops progressus*

BT (Bugin Mem. of Naran Bulak Fm., Bugin Tsav Basin, Mongolia)

Khaychina elongata, *Archaeolambda trofimovi*, *Prodinoceras* sp., *Zagmys insolitus*

DB (Dabu Fm., Turfan Basin, Xinjiang)

Coryphodon dabuensis, *Prodinoceras xinjiangensis*

PH (Pinghu Fm., Chijiang Basin, Jiangxi)

Prodinoceras lacustris (*australis*)

LM (Limuping Fm., Hengyang Basin, Hunan)

Archaeolambda cf. *A. planicanina*

KZ (Tashkentskie Chuli Area, Dzhalga locality, Southern Kazakhstan)

Jarveia minuscula, *Voltaia minuta*

Bumbanian Land Mammal Age

WT (Wutu Fm., Wutu Basin, Shandong)

Mesodmops dawsonae, *Auroratherium sinense*, *Asioictops mckennai*, *Scileptictis simplus*, ?*S. stenotalus*, *Luchenus erinaceanus*, *Hylomysoides qiensis*, *Qilulestes schieboutae*, *Changlelestes dissetiformis*, *Talpilestes asiatica*, *Suyinia changleensis*, *Yupingale weifangensis*, *Asioplesiadapis youngi*, *Carpocristes oriens*, *Chronolestes simul*, cf. *Ignacius* sp. n., *Dianomomys ambiguous*, *Alagomys oriens*, *Bandaomys zhonghuaensis*, *Acritoparamys wutui*, ?*Acritoparamys* sp., *Taishanomys changlensis*, *T. parvulus*, *Oxyaena* sp., *Anthracoxyaena palustris*, *Preonictis youngi*, *Variviverra vegetates*, *Zodiocyon zetesios*, *Parresthonyx orientalis*, *Yuesthonyx* sp., *Hapalodectes huanghaiensis*, *Dissacus bohaisensis*, *Celaenolambda wangzhaoi*, *Wutucoryphodon xianwui*, ?*Heterocoryphodon yuntongi*, ?*Mongolotherium* sp., *Migrostylops roboreus*, *M. rosella*, *Lophocion asiaticus*, *Asiohyopsodus confuciusi*, *Pappomoropus taishanensis*, *Chouliia laoshanensis*, *Chouliia* cf. *C. laoshanensis*, *Homogalax wutuensis*, *Homogalax* sp., ?*Homogalax* sp., cf. *Protictis* sp. n., *Ampholophus luensis*, *Wutuhys primiveris*, *Olbitherium millenarianicus*, ?*Micromomyidae* gen. et sp. n., *Rodentia* indet.

BB (Bumban Mem. of Naran Bulak Fm., Nemegt Basin, Mongolia)

Naranianus infrequens, *Tsaganius ambiguous*, cf. *Hyracolestes* sp., *Bumbanius rarus*, *Oedolius perexiguus*, *Altanius orlori*, *Zagmys insolitus*, *Gomphos elkema*, *Decipomys mongoliensis*, *Rhombomylus* cf. *R. turpanensis*, *Alagomys inopinatus*, *Sharomys singularis*, *S. parvus*, *Kharomys mirandus*, *K. gracilis*, *Tsaganmys subitus*, *Ulanomys mirificus*, *Orogomys obscurus*, *Ivanantonia efremovi*, *Adolomys ameristua*, *Tsaganikhushumys deriphatus*, *Bumbanomys edustus*, ?*Esesempomys centralasiae*, *Eomyilus zhigdenensis*, *Hapalodectes* sp., *Hyopsodus orientalis*, *Archaeolambda* sp. n., *Arctostylops* sp., ?*Orientolophus* (*Homogalax*, Dashzeveg et al., 1988) *namadicus*, ?*Orientolophus* (*Hyracotherium*, Dashzeveg et al., 1998) *gabuniai*, *Prodinoceras efremov*, *Tsaganohyus pecus*, *Midiagnus gracilis*, *Prosarcodon maturus*, *Edzenius lus*, *Eosoricodon terrigema*, *Ordo-*

- lestes ordinatus*, *Bagalestes trofimovi*, *Arnebolagus leporinus*, Pantolestidae gen. indet., Nyctitheriidae gen. indet., Lepotyphla indet.
- KY (Lower Alay beds, Andarak fauna, Kyrgyzstan)
Sarcodon (*Metasarcodon*) *udovichenkoi*, *Anatolmys* *rozdestvenskii*, *Aktashmys montealbus*, *Valerilagus reshetovi*, *Petrokzovia* cf. *P. notos*, *Saykanomys* cf. *S. bohlini*, *Advenimus* cf. *A. burkei*, *Khodzhentia vinogradovi*, *Alaymys ctenodactylus*, ?*Adolomyss* sp., *Neoparapterodon* n. sp., ?*Eomorops* sp. or ?cf. *Propachynolophus* sp., *Pataecops minutissimus*, *Eoletes* sp., ?*Lophialetes* sp., *Forstercooperia* sp., *Diacodexis* sp., *Eolantianius russelli*, ?*Eolantianius russelli* gen. et sp. n., *Pilgrimella* sp., *Eoletes tianshanicus*, *Protogalericius averianovi*, *Teleolophus medius*, *Sharamynodon kirghisensis*, *Nuryctes alayensis*, *Gobiolagus hekkeri*, Palaeoryctidae gen. et sp. indet., Hyaenodontidae gen. et sp. n., Lipotyphla gen. sp. indet., Ctenodactyloidea indet., Mesonychidae indet., *Diacodexis* indet.
- LC (Lingcha Fm., Hengyang Basin, Hunan)
Hsiangolestes youngi, cf. *Naranium* sp., *Teilhardina asiatica*, *Matuinia nitidulus*, *Cocomys lingchaensis*, cf. *Tsagamys* sp., *Dissacus zengi*, *Hapalodectes hetangensis*, *Asiocoryphodon* sp., *Hunanictis inexpectatus*, *Orientalophus hengdongensis*, *Propachynolophus hengyangensis*, Insectivora gen et sp. n.
- YH (Yuhuangding Fm., Xichuan Basin, Henan)
Rhombomylus sp., *Advenimus hupeiensis*, *Asiocoryphodon conicus*, *A. lophodotus*, *Heterocoryphodon flerowi*, *Menteodon* cf. *M. youngi*, cf. *Heptodon* sp., *Danjiangia pingi*, *Hohomys lii*, *Gobiatherium* sp., Cocomyidae gen. et sp. indet.
- SS (Shisanjianfang Fm., Turfan Basin, Xinjiang)
Rhombomylus turpanensis, *Anatolostylops dubius*, *Hyopsodus* sp., *Coryphodon* sp., *Heptodon tianshanensis*
- NM (U) (Upper part of Nomogen Fm., Erlian, Nei Mongol)
Gomphos elkema, *Gomphos* sp., *Baataromomys ulaanus*, *Anatolostylops* sp. nov., ?*Pataecops parvus*, *Dissacus* sp, rodents, lagomorph, creodont, ?artiodactyl
- NJ (Ningjiashan Mem. of Xinyu Group, Yuanshui Basin, Jiangxi)
Xinyuictis tenuis, *Coryphodon ninchiashanensis*, *Prodinoceras sinyuensis*, ?*Heptodon* sp.
- LP (Leipi beds, Danjiangkou area, Hubei)
Rhombomylus cf. *R. tupanensis*, *Hannanomys lini*
- ZSJ (Zhangshanji Fm., Laian Basin, Anhui)
Rhombomylus laianensis
- NSH (Niushan Mem. of Wutu Fm., Niushan Basin, Shandong)
Heptodon niushanensis
- YP (Youping Fm., Fangxian County, Hubei)
Hyopsodus fangxianensis
- UN (Mem. II, III of Khashat (Gashato) Fm., Ulan Nur Basin, Mongolia)
Gomphos elkema
- AT (Aguyt Mem. of Naran Bulak Fm., Nemegt Basin, Mongolia)
Gomphos elkema
- ZHG (Zhylga 1b, Kazakhstan)
 Artiodactyla inc. sed., Diacodexidae indet.