Chinese Continental Paleocene-Eocene Boundary and Its Correlation

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Abstract: Recent paleontological, paleomagnetic and carbon isotopic investigations have provided new evidence supporting placement of the Chinese terrestrial Paleocene–Eocene boundary at the base of the Lingcha Formation in the Hengyang Basin, Hunan Province, and within the upper part of the Nomogen Formation in the Erlian Basin, Inner Mongolia. Based on mammalian and ostracod biostratigraphic data, the boundary can also be roughly correlated with the contacts between the Baoyue and Huayong formations in the Sanshui Basin of Guangdong, the Qingjiang and Xinyu formations of Jiangxi, the Fourth Formation of the Funing Group and the Dainan Formation in northern Jiangsu, and the Dabu and Shisanjianfang formations in the Turfan Basin of Xinjiang.

Key words: Vertebrate/ostracod biostratigraphy, Paleocene–Eocene boundary, correlation, Hunan Province, Inner Mongolia, China

1 Introduction

In the course of the transition between the Paleocene and Eocene epochs, the annual average temperature at the bottom of the ocean increased 4–6°C, whereas sea surface temperatures (SSTs) increased 5°C near the equator and 5–10°C in medium- and high-latitude areas (Domingo et al., 2009; Kennett and Stott, 1991; Scheibner and Speijer, 2009; Sluijs et al., 2006, 2009; Weijers et al., 2007; Zachos et al., 2001, 2003, 2006). This event was originally referred to as the Late Paleocene Thermal Maximum (LPTM) (Zachos et al., 1993, 2001) and is now termed the Paleocene–Eocene boundary Thermal Maximum (PETM) (Aubry et al., 2007). It is unquestionably related to a negative 2.5 to 4‰ carbon isotope excursion (CIE) in the marine record (Shackleton, 1986; Zachos et al., 1993, 2001) that occurs in the lower to mid-chron C24r of the Geomagnetic Polarity Time Scale (GPTS) (Zachos et al., 2001). The CIE has also been recorded in the terrestrial deposits of the Bighorn Basin, Wyoming, USA (Koch et al., 1992). In August 2004, the International Union of Geological Sciences (IUGS) ratified a proposal to place the Global Stratotype Section and Point (GSSP) for the base of the Eocene Series (i.e., the Paleocene–Eocene [P–E] boundary) in the Section DBH in the Dababiya Quarry, about 35 km south of Luxor, Egypt. The CIE was used as the primary criterion to establish the boundary (Aubry et al., 2007; Magioncalda et al., 2004).

The PETM was accompanied by significant biotic events in both marine and terrestrial environments. Three major groups of mammals, artiodactyls, perissodactyls and euprimates made an abrupt appearance on all three northern continents at the beginning of the Eocene Epoch (Gingerich, 2006; Romer, 1966; Savage and Russell, 1983). However, the position of the P–E boundary in continental deposits has long been in dispute (Gingerich, 2001). Recently, the boundary was accepted as roughly correlative with the base of Wasatchian Land Mammal Age in North America, according to the CIE record (Bowen et al., 2001; Gingerich, 2006; Woodburne, 2004).

Terrestrial Paleocene and Eocene strata have a wide distribution in China, but at the majority of sites the P–E boundary is clearly absent. Mammal-based biostratigraphic studies do not provide a basis for precise demarcation of the P–E boundary in any case. In addition, disputes pertaining to the ages of some strata (Huang and Zheng, 1997; Qiu et al., 1977; Yang et al., 1979) have also hampered the accurate identification of this boundary at certain sites. In 2000, a synthetic study of magnetostratigraphy, chemostratigraphy, and mammalian biostratigraphy related to the P–E boundary in the Lincha area of the Hengyang Basin, Hunan was conducted by a joint research group of Chinese and American researchers, which resulted in the first record of the CIE in continental deposits outside North America (Bowen et al., 2002; Ting

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et al., 2003). Subsequently, discovery of mammals characteristic of the Eocene-age Bumbanian biozone of Mongolia in the upper part of the supposedly late Paleocene Nomogen Formation of Inner Mongolia (Meng et al., 2004), together with preliminary paleomagnetic work (Bowen et al., 2005), indicated the presence of the P–E boundary in the Erlian Basin, Inner Mongolia, China. Discussion of the P–E boundary in this paper is based mainly on recent work in the Erlian Basin and in the Hengyang Basin of Hunan Province where the boundary also occurs (Fig. 1).

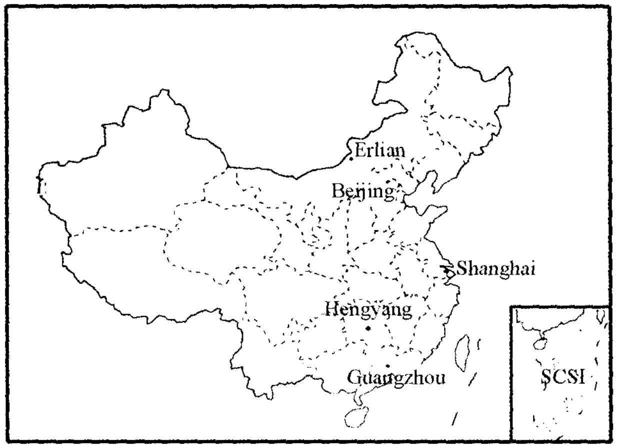

Fig. 1. Sketch map showing the location of the Hengyang Basin, Hunan Province and the Erlian Basin, Inner Mongolia.

2 P–E Boundary Section in the Lingcha Area, Hengyang Basin, Hunan

The Hengyang Basin is located in southern Hunan Province and consists of Cretaceous and Paleogene red beds. Three Paleogene sections, named Fukuitang-Lingcha (section 1), Limuping (section 2) and Tianzhifen-Jixianwan (section 3), have been reported from the basin. The Paleogene deposits in the Lingcha area are subdivided into two formations: the upper Paleocene Limuping Formation and the lower Eocene Lingcha Formation, with the boundary at the level of 231.6 m in section 3 (Tong et al., 2006).

Discovery of the perissodactyl *Propachynolophus hengyangensis* near Lingcha town (originally called Zhenbiling), Hengdong County confirmed the occurrence of Eocene deposits in the basin (Li et al., 1979a; Young and Bien, 1938; Young, 1944). The fossil mammals from the top layers of sections 1 and 3 near Lingcha form an assemblage that is considered representative of early Eocene faunas (Li and Ting, 1983; Russell and Zhai, 1987; Tong et al., 1995; Wang et al., 2006, 2007). However, the presence of Paleocene strata has been a matter of long-standing dispute (Ge et al., 1994; Guan, 1989; Zheng and Qiu, 1979), although two lower jaw fragments of a pantodont *Archaeolambda* sp., associated with a crocodylid *Planocrania hengdongensis*, have been recovered from an exposure near Limuping (Li et al., 1979a; Li, 1984).

2.1 Paleontological evidence

2.1.1 Mammals

Mammalian fossils have a special significance in terrestrial Cenozoic biostratigraphy. Two major mammal-bearing horizons have been recognized in the Lingcha area (Fig. 2). The lower one (M-LMP) occurs within the Limuping Formation at the site and section of the same name, and is distinguished by the presence of the pantodont *Archaeolambda* sp., and the upper one (M-LC) occurs in the Lingcha Formation at both the Fukuitang-Lingcha and the Tianzhifen-Jixianwan sections (Li et al., 1979a; Ting et al., 2003; Tong et al., 2006). Fossil mammals reported from the upper horizon include: the insectivores *Hsiangolestes youngi* and cf. *Naranius infrequens*; the mixodont *Matutinia nitidulus*; the rodents *Cocomys lingchaensis* and cf. *Tsagamys subitus*; the mesonychians *Hapalodectes hetangensis* and *Dissacus zengi*; the coryphodontid pantodont *Asiocoryphodon*? sp.; the omomyid euprimate *Teilhardina asiatica*; the perissodactyls *Orientolophus hengdongensis* and *Propachynolophus hengyangensis*; and the proeutherian *Hunanictis inexpectatus* (Li et al., 1979a, 1979b; Ni et al., 2004; Ting and Li, 1987; Ting, 1993; Ting et al., 2004; Zheng and Huang, 1984).

The Asian genus *Archaeolambda* has a wide distribution in Paleocene deposits of both China and Mongolia, but has not been recorded in Eocene strata (Russell and Zhai, 1987; Ting, 1993, 1998; Tong et al., 1995; Wang et al., 1998, 2007), and is thus considered to be a late Paleocene index fossil in eastern Asia. Thus the strata yielding *Archaeolambda* in the Lingcha area are probably of upper Paleocene age. On the other hand, none of the fossil mammals of the upper assemblage is exclusively found in the Paleocene. Among them, *Teilhardina* has been recorded in earliest Eocene sediments in both North America and Europe (Bown, 1976; Bown and Rose, 1987; Gingerich, 1993; Rose, 1994; Russell et al., 1967; Simpson, 1940; Teilhard de Chardin, 1927); *Tsagamys subitus* and *Naranius infrequens* occur in the earliest Eocene Bumbanian mammal fauna of Mongolia (Dashzeveg, 1988, 1990; Russell and Dashzeveg, 1986); *Orientolophus* also occurs in Bumbanian strata (Dashzeveg, 1988, 1990; Hooker and Dashzeveg, 2004; Russell and Dashzeveg, 1986; Ting, 1993), whereas *Propachynolophus* was originally reported

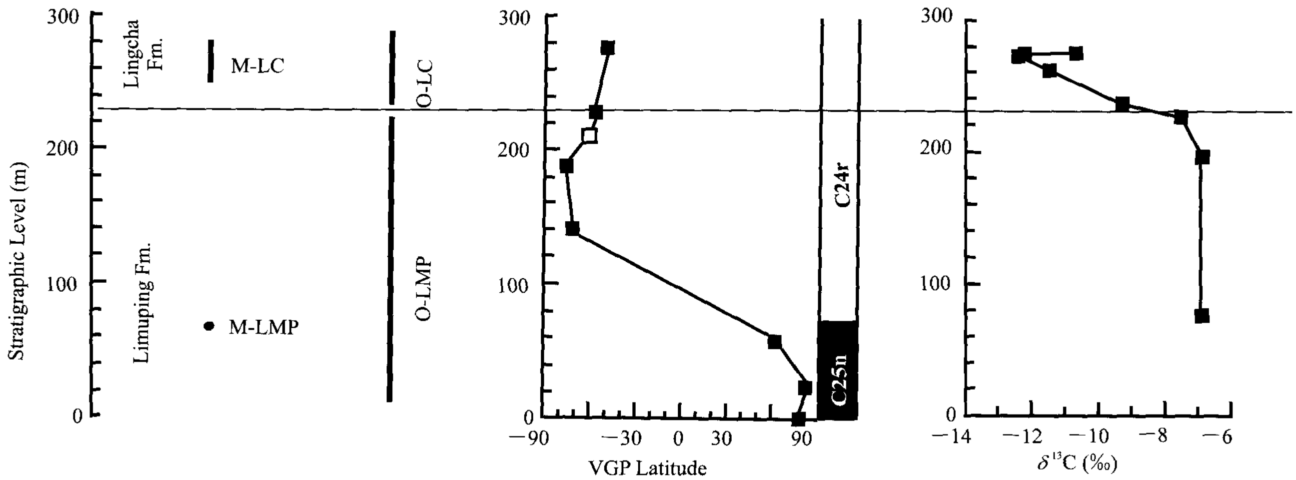

Fig. 2. Paleomagnetic and carbon isotope data (modified from Ting et al., 2003) and the distribution of fossil mammal and ostracod assemblages at the Tianzhifen–Jixianwan section, Hengyang Basin, Hunan. The closed symbols in the VGP latitude plot represent sites with four or more stable samples, which are significantly clustered at $p < 0.01$, whereas the open symbols indicate sites that fall short of this standard but have three or more stable samples significantly clustered at $p < 0.05$ or two samples significantly clustered at $p < 0.01$.

M-LC: Mammal-bearing horizon in the Lingcha Formation; M-LMP: Mammal-bearing horizon in the Limuping Formation, known from the Limuping section; O-LC: Ostracod assemblage of the Lingcha Formation; O-LMP: Ostracod assemblage of the Limuping Formation.

from the early Eocene of Europe (Li et al., 1979a; Savage et al., 1965). The age of the upper assemblage has been unequivocally determined to be early Eocene (Li et al., 1979a; Ting, 1998; Tong et al., 1995; Tong et al., 2006; Wang et al., 2006, 2007).

2.1.2 Ostracods

The Paleogene deposits in the Lingcha area are also rich in fossil ostracods. Two assemblages have been recognized (Fig. 2): the lower one (O-LMP) is the *Cypris henanensis–Cypris reinformis–Limnocythere honggangensis* assemblage, characterized by high abundance of smooth-shelled *Cypris henanensis* and non-decorated *Limnocythere honggangensis*; the upper one (O-LC) is the *Limnocythere irregularis–Cypris favosa–Ilyocypris gaoyouensis* assemblage. Two species of *Limnocythere* that are both well-decorated with tubercles, *L. spinisalata* and *L. irregularis*, are very common in the upper assemblage. The strata containing the lower assemblage correspond to the Limuping Formation, whereas those containing the upper assemblage correspond to the Lingcha Formation. Their respective ages are late Paleocene and early Eocene (Zhang and Li, 2010).

2.2 Magnetostratigraphic and chemostratigraphic evidence

In 2000, a joint field team of Chinese and American scientists revisited the Hengyang Basin. Magnetostratigraphic and chemostratigraphic studies of three sections provided further evidence for the P–E boundary in the Hengyang Basin (Fig. 2). Four polarity intervals were recorded in section 1, and two intervals were recorded in section 3. The typical early Eocene mammalian fossils from the Lingcha Formation confirmed that the uppermost reversed-polarity intervals at the two sections are equivalent, and also correlate with Chron C24r of GPTS (Bowen et al., 2002; Ting et al., 2003, 2004). Carbon isotope analysis indicated that average $\delta^{13}C$ values remain nearly constant at approximately −7‰ through most of the sampled intervals in sections 1 and 3. However, significantly lower $\delta^{13}C$ values were recorded in the upper parts of both sections. In section 1, a single level at 548 m contains nodules with an average $\delta^{13}C$ value of −12.5‰. In section 3, the carbonate nodule $\delta^{13}C$ values decrease from 238 m to 274 m, reaching a minimum of −12.7‰, and then rebound slightly at the top of the section (Table 1). The transient carbon isotope shift recorded in sections 1 and 3 was correlated with the P–E boundary CIE. Biostratigraphic and paleomagnetic results also supported this correlation (Bowen et al., 2002; Ting et al., 2003).

Table 1 Average $\delta^{13}C$ values for the Tianzhifen–Jixianwan section, Hengyang Basin, Hunan

	Level (m)	Average $\delta^{13}C$ (‰)
Limuping Formation	76.8	-7.2
	198	-7.1
	228.6	-7.8
Lingcha Formation	238.4	-9.6
	262.8	-11.7
	271.8	-12.7
	274.2	-12.5
	276	-10.9

Table 2 Correlation of the P–E boundary across selected terrestrial basins of China

Age	Hengyang, Hunan	Sanshui, Guangdong	Qingjiang, Jiangxi	Northern Jiangsu	Turfan, Xinjiang	Erlian, Inner Mongolia
Early Eocene	Lingcha Fm.	Huayong Fm.	Xinyu Fm.	Dainan Fm.	Shisanjianfang Fm.	Nomogen Fm.
Late Paleocene	Limuping Fm.	Baoyue Fm.	Qingjiang Fm.	Fourth Fm. of Funing Group	Dabu Fm.	

2.3 Position of the P–E boundary

Paleontological, paleomagnetic and carbon isotopic evidence all suggest a very early Eocene age for the mammal-bearing strata of the Lingcha Formation in the Hengyang Basin, Hunan (Ting et al., 2003; Tong et al., 2006). The boundary between the Lingcha Formation and the Limuping Formation, which occurs at the level of 231.6 m in section 3, was considered equivalent to the P–E boundary (Tong et al., 2006). Another possible placement of the boundary is within the Lingcha Formation at the level of 238 m in section 3. This represents the lowest level at which the CIE has been recorded, and the beginning of the CIE has been chosen as the primary correlative element for the P–E boundary (Aubry et al., 2007). However, the basal sandstone of the Lingcha Formation at the level of 231.6–237 m could not be sampled for carbon isotope analysis because of lacking paleosols, and there is a gap of nearly 10 meters between the lowest sampling level in the Lingcha Formation and the uppermost sampling level in the Limuping Formation (Table 1).

For the sake of easy recognition, it is reasonable to accept the base of the Lingcha Formation as the P–E boundary in the Lingcha area, Hunan (Table 2).

3 P–E Boundary Section at Nuhetingboerhe, Erlian Basin, Inner Mongolia

The Erlian Basin is one of the most important Paleogene terrestrial basins, and is located in the central part of Inner Mongolia, China (Fig. 1). It has been a major source of data for studies of Paleogene vertebrate paleontology and stratigraphy since the pioneering work by the Central Asiatic Expeditions (CAE) of the American Museum of Natural History in the 1920s. A number of lithological units were proposed on the basis of the Paleogene deposits, such as the Irdin Manha Formation, the Arshanto Formation, the Shara Murun Formation, the Ulan Gochu Formation, the Ulan Shireh Formation, etc. (Berkey and Morris, 1927; Berkey et al., 1929; Granger and Berkey, 1922). Many Asian land mammal ages were named after the mammalian faunas derived from these formations (Luterbacher et al., 2004; Romer, 1966; Russell and Zhai, 1987; Tong et al., 1995; Wang et al., 2006, 2007). However, deposits pre-dating the middle Eocene were not reported in the Erlian Basin until 1976, when the upper Paleocene Nomogen Formation was proposed (Zhou et al., 1976). The discovery of the Mongolian early Eocene Bumbanian glire *Gomphos elkema* in the upper part of the Nomogen Formation in the Huheboerhe area confirmed the presence of lower Eocene strata (Meng et al., 2004) and indicated the possible existence of the P–E boundary in the Erlian Basin. Preliminary paleomagnetic results suggested that the *Gomphos*-bearing bed was in Chron C24r of the GPTS (Bowen et al., 2005). Further investigation in the Huheboerhe area resulted in the recognition of four mammalian assemblages of late Paleocene and early Eocene age in the Nomogen Formation at the Nuhetingboerhe section, 5 km north of the Wulanboerhe section (Meng et al., 2007) (Fig. 3).

3.1 Mammalian paleontological evidence

The Nuhetingboerhe section contains strata from both the Nomogen Formation and the Arshanto Formation (Meng et al., 2007). The Nomogen Formation (37.5 m thick) is mainly red mudstone, silty mudstone and siltstone, with fine to medium-grained sandstone lenses. It is disconformably overlain by the grayish white coarse sandstone of the basal part of the Arshanto Formation (Meng et al., 2007). As mentioned above, fossil mammals from the Nomogen Formation fall into four assemblages (A–D in Fig. 3). The lowest one, assemblage A, is at the level of 5.1–8.5 m in the Nuhetingboerhe section and consists of typical late Paleocene forms such as *Lambdopsalis bulla*, *Prionessus lucifer*, *Bayanulanius tenuis*, *Tribosphenomys minutes*, *Eomylus borealis*, *Pseudictipos lophiodon*, *Prodinoceras xinjiangensis* and *Palaeostylops iturus*. (Wang et al., 2009). Only a few kinds of mammals were found at the 22–23 m level, but these make up assemblage B. They are also typical of the late Paleocene, and include *Pastoralodon lacustris* and *Lambdopsalis bulla*. Assemblage C occurs at the level of 30.5–32 m, which is rich in large and irregular calcareous nodules and has special significance for biostratigraphic determination of the P–E boundary in the Erlian Basin. The first early Eocene mammal known from the basin, *Gomphos elkema*, was found in the same beds at the Wulanboerhe section (misidentified as the Huheboerhe section in the original report) (Meng et al., 2004), about 5 km south of the Nuhetingboerhe section. This assemblage comprises several fossil mammals, including *Gomphos elkema*, *Baataromomys ulaanus*, *Anatolostylops zhaii*, *Pataecops parvus*, an unnamed new lophialetid, *Dissacus* sp., an unnamed new ctenodactyloid, and Lagomorpha indet. (Meng et al., 2004; Ni et al., 2007; Wang et al., 2008a, 2008b, 2009). Since *Gomphos elkema* is the most common mammal in assemblage C, the strata containing mammals of this assemblage are called the *Gomphos*-bearing beds. The presently known mammals of assemblage D include *Uintatherium* sp. (Bai, 2006), *Gomphos elkema*, *Pataecops parvus*, and Ctenodactyloidea indet.

The fossil mammals from assemblages A and B are typical of the late Paleocene Gashatan forms known from both China and Mongolia (Chow and Qi, 1978; Li and Ting, 1983; Meng and McKenna, 1998; Meng et al., 1998; Ting, 1998; Wang et al., 1998, 2006, 2007). They have never been reported from early Eocene deposits anywhere in the world. In contrast, the upper two assemblages (C and D) are considered to be correlative to the Mongolian Bumbanian mammal fauna, as indicated by the presence of *Gomphos elkema* (Meng et al., 2004; Wang et al., 2008b). The Bumbanian fauna has been widely accepted as a representative of the early Eocene faunas (Dashzeveg, 1988; Luterbacher et al., 2004; Meng and McKenna, 1998; Russell and Zhai, 1987; Ting, 1998; Wang et al., 2006, 2007). Based on the currently available paleontological data, the P–E boundary in the Huheboerhe area most probably falls within a 7-meter interval, between the levels of 23 m and 30.5 m in the Nuhetingboerhe section.

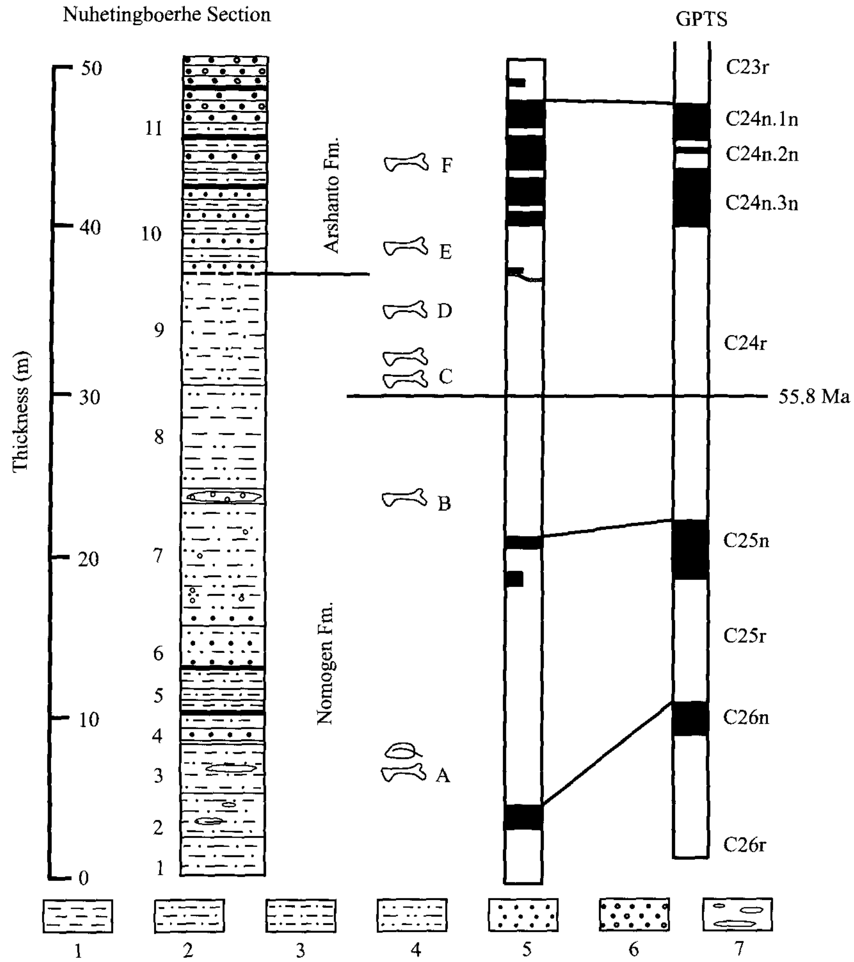

Fig. 3. Paleomagnetic correlations and distribution of fossil mammals at the Nuhetingboerhe section, Erlian Basin, Inner Mongolia (Note: A–F indicate mammal-bearing horizons. Paleomagnetic results after Sun et al. (2009).

1, mudstone; 2, sandy clay; 3, silty mudstone; 4, muddy siltstone; 5, fine sandstone; 6, coarse sandstone; 7, sandstone lense.

3.2 Magnetostratigraphic evidence

Bowen et al. (2005) reported preliminary results of paleomagnetic work and correlated the *Gomphos*-bearing strata of the Wulanboerhe section with the interval of time represented by Chron C24r of the GPTS. Further paleomagnetic investigation of the Nuhetingboerhe section provided a similar but more detailed result (Sun et al., 2009).

In the recent paleomagnetic study, the Nomogen Formation in the Nuhetingboerhe section was found to exhibit 5 polarity intervals that were correlated to Chrons C26r - C24r of the GPTS (Sun et al., 2009). Mammal assemblages B–D are all in the reversed polarity interval of Chron C24r, while assemblage A is in the lower part of Chron C25r. This result provided new evidence that facilitates recognition of the P–E boundary in the Huheboerhe area on the basis of paleontological data (Sun et al., 2009).

3.3 Position of the P–E boundary in the Huheboerhe Area

The deposits in the P–E boundary interval are continuous and without significant facies changes, which makes the boundary easier to locate. Possibly due to very low sediment accumulation rates, our carbon isotopic analysis does not appear to have recovered evidence of the CIE that normally marks the P–E boundary (Bowen et al., 2005). This hampered precise correlation of the local P–E boundary with the global standard. As mentioned above, however, paleontological and paleomagnetic studies have provided useful information that helps establish the position of the P–E boundary in the Huheboerhe area. Based on the currently available paleontological and magnetostratigraphic data, it is probable that the P–E boundary lies at the base of the *Gomphos*-bearing bed, at about the 30-meter level in the Nuhetingboerhe section. This conclusion is consistent with paleomagnetic results (Sun et al., 2009). The 20–30 cm thick basal red mudstone of the *Gomphos*-bearing bed, containing grayish white, relatively large and irregular calcareous nodules, can be used as a reliable field indicator of the P–E boundary in the Erlian Basin.

4 Correlation of the P–E Boundary in Selected Basins

The terrestrial Paleogene has a wide distribution in China, but continuous P–E boundary sequences have been proven to exist at only a few locations. To date, the only continuous boundary P–E sections for which both magnetostratigraphic and chemostratigraphic studies have been reported are the examples discussed above from the Lingcha area, Hengyang Basin, Hunan (Bowen et al., 2002; Ting et al., 2003) and the Huheboerhe area, Erlian Basin, Inner Mongolia (Meng et al., 2007; Sun et al., 2009; Wang et al., 2008b). Paleomagnetic and carbon isotopic studies of these sections provide a firm basis for correlating the P–E boundary with mammal and ostracod biostratigraphic indicators. The following discussion on interbasinal correlation of the terrestrial P–E boundary will therefore be based on paleontological data pertaining to fossil mammals and ostracods.

According to currently available information, only one area producing Paleogene mammalian fossils, apart from the Lingcha and Huheboerhe areas, has the potential to contain P–E boundary sections. This third area is in the eastern part of the Turfan Basin. The Paleogene strata that may contain the P–E boundary are the Dabu Formation and the overlying Shisanjianfang Formation. The two formations contact conformably in a section about 38 km south of the Dabu train station (Zhai et al., 1978). The Dabu Formation was originally considered to be early Eocene in age and possibly equivalent to the North American Clarkforkian, based on comparisons of the coryphodontid pantodont *Coryphodon dabuensis* with the North American *Coryphodon proterus* and the European *C. eocanus* (Zhai, 1978b). The Clarkforkian North American Land Mammal Age is now considered to be of late Paleocene age (Aubry et al., 2007; Bowen et al., 2001; Gingerich, 2001). Reexamination of another mammal of the Dabu Formation led to reassignment of the dinoceratan "*Pyrodon*" *xinjiangensis* to the genus *Prodinoceras* (Schoch and Lucas, 1985), a genus typical of and widely distributed in Asian late Paleocene deposits (Wang et al., 1998). Fossil mammals found in the Shisanjianfang Formation include some typical early Eocene forms, such as *Hyopsodus* sp., *Heptodon tianshanensis*, *Rhombomylus turpanensis*, and *Anatolostylops dubius* (Zhai, 1978a). Among them, the arctostylopid *Anatolostylops dubius* is very similar to *A. zhaii* from assemblage C of the Nomogen Formation in the Erlian Basin, Inner Mongolia (Wang et al., 2008b). The P–E boundary in the eastern Turfan Basin is probably falls between the mammal-bearing beds of the Dabu Formation and those of the Shisanjianfang Formation. It is acceptable to provisionally place the boundary at the contact between the two formations pending more detailed study.

Paleocene–Eocene ostracods have been reported from several terrestrial Paleogene basins in China. Some of these basins, including the Sanshui Basin in Guangdong (Zhang et al., 2008), the Qingjiang Basin in Jiangxi (Liu, 1982), and the North Jiangsu Basin (Hou et al., 1982), can be inferred to have high potential to contain the P–E boundary based on the recent work in the Lingcha area. The ostracod assemblages in these candidate basins are highly comparable to those documented in the Lingcha area. The ostracod assemblage from the Limuping Formation can be correlated with those of the Baoyue Formation in the Sanshui Basin, the Qingjiang Formation in the Qingjiang Basin, and the Fourth Formation of the Funing Group in northern Jiangsu, while the ostracod assemblage from the Lingcha Formation correlates with those of the Huayong Formation in the Sanshui Basin, the Xinyu Formation in the Qingjiang Basin, and the Dainan Formation in northern Jiangsu (Zhang and Li, 2010). The P–E boundary can be tentatively placed between the Lingcha-equivalent and Limuping-equivalent formations in each of the above mentioned basins.

5 Conclusions

(1) Recent investigations of the P–E boundary, especially magnetostratigraphic and chemostratigraphic studies, have provided evidence for relatively precise correlations of the Chinese terrestrial P–E boundary with both the global standard and the North American local terrestrial P–E boundary. Based on such work, the Chinese terrestrial P–E boundary can be confidently placed at the base of the Lingcha Formation in the Hengyang Basin, Hunan Province, and within the upper part of the Nomogen Formation in the Erlian Basin, Inner Mongolia.

(2) Simultaneous paleontological, paleomagnetic and carbon isotopic research at the same sections has established relationships between fossil sequences and geomagnetic and carbon isotopic records, which allows

more precise biostratigraphic correlation of the P–E boundary across the different terrestrial Paleogene basins.

(3) Based on biostratigraphic correlations, the P–E boundary is roughly correlated with the contacts between the Huayong/Baoyue formations in the Sanshui Basin of Guangdong Province, the Xinyu/Qingjiang formations of Jiangxi Province, the Dainan Formation/Fourth Formation of the Funing Group in northern Jiangsu Province, and the Shisanjianfang/Dabu formations in the Turfan Basin of Xinjiang Uygur Autonomous Region.

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