A synopsis of Paleocene stratigraphy and vertebrate paleontology in the Qianshan Basin, Anhui, China Postprint

Authors: WANG Yuan-Qing, LI Chuan-Kui, LI Qian, LI Ding-Sheng

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Abstract

The Mesozoic and Cenozoic redbeds in the Qianshan Basin comprise a set of monocline clastic rocks and are subdivided into the Late Cretaceous Gaohebu Formation, the Paleocene Wanghudun Formation (including the Lower, Middle, and Upper members) and Doumu Formation (including the Lower and Upper members). Continuous investigations in the Qianshan Basin since 1970 have resulted in the discovery of numerous vertebrate specimens. To date, 61 species (including 9 unnamed ones) in 45 genera of vertebrates, representing reptiles, birds and mammals, have been reported from the Paleocene of the Qianshan Basin. Among them, mammals are the most diverse group and have been classified into 46 species (7 unnamed) of 33 genera, representing 16 families in 10 orders. According to their stratigraphic occurrence, seven fossiliferous horizons can be recognized in the Qianshan Paleocene. Based on the evidence of mammalian biostratigraphy, the strata from the Lower Member through the lower part of the Upper Member of Wanghudun Formation could be roughly correlated to the Shanghu Formation of the Nanxiong Basin (Guangdong Province) and the Shizikou Formation of the Chijiang Basin (Jiangxi Province), corresponding to the Shanghuan Asian Land Mammal Age (ALMA). Both the upper part of the Upper Member of Wanghudun Formation and the Doumu Formation could be correlated to the Nongshan Formation of the Nanxiong Basin and the Chijiang Formation of the Chijiang Basin, corresponding to the Nongshanian ALMA. Paleomagnetic results from several Chinese Paleocene basins suggest that the Shanghuan is roughly correlative to the Puercan and Torrejonian North American Land Mammal Ages (NALMA), while the Nongshanian correlative to the early to middle Tiffanian (Ti1–4a). The Shanghuan and the Nongshanian are probably correlated to the Danian and the Selandian of the Global Geologic Time Scale. Therefore, all the fossil vertebrates collected in the Qianshan Basin are of Early and Middle Paleocene age.

Full Text

Preamble

A Synopsis of Paleocene Stratigraphy and Vertebrate Paleontology in the Qianshan Basin, Anhui, China

WANG Yuan-Qing[1], LI Chuan-Kui[1], LI Qian[1], LI Ding-Sheng[2]
[1]Key Laboratory of Vertebrate Evolution and Human Origins of Chinese Academy of Sciences, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Beijing 100044
[2]Qianshan County Museum, Qianshan, Anhui 246300

Abstract

The Mesozoic and Cenozoic redbeds in the Qianshan Basin comprise a set of monocline clastic rocks subdivided into the Late Cretaceous Gaohebu Formation, the Paleocene Wanghudun Formation (including Lower, Middle, and Upper members), and the Doumu Formation (including Lower and Upper members). Continuous investigations since 1970 have yielded numerous vertebrate specimens. To date, 61 species (including 9 unnamed) in 45 genera of vertebrates —representing reptiles, birds, and mammals—have been reported from the Paleocene of the Qianshan Basin. Mammals are the most diverse group, with 46 species (7 unnamed) in 33 genera representing 16 families in 10 orders. Based on stratigraphic occurrence, seven fossiliferous horizons can be recognized. Mammalian biostratigraphic evidence indicates that strata from the Lower Member through the lower part of the Upper Member of the Wanghudun Formation correlate roughly with the Shanghu Formation of the Nanxiong Basin (Guangdong Province) and the Shizikou Formation of the Chijiang Basin (Jiangxi Province), corresponding to the Shanghuan Asian Land Mammal Age (ALMA). The upper part of the Upper Member of the Wanghudun Formation and the Doumu Formation correlate with the Nongshan Formation of the Nanxiong Basin and the Chijiang Formation of the Chijiang Basin, corresponding to the Nongshanian ALMA. Paleomagnetic results from several Chinese Paleocene basins suggest the Shanghuan correlates roughly with the Puercan and Torrejonian North American Land Mammal Ages (NALMA), while the Nongshanian correlates with the early to middle Tiffanian (Ti1–4a). The Shanghuan and Nongshanian probably correspond to the Danian and Selandian of the Global Geologic Time Scale. Therefore, all fossil vertebrates collected in the Qianshan Basin are Early and Middle Paleocene in age.

Key words: Qianshan, Anhui; Paleocene; vertebrates; stratigraphy; correlation

1 Introduction

The Qianshan Basin, located in southwestern Anhui Province, China, is a small foreland basin on the east side of the Dabie Mountains, encompassing parts of Qianshan, Tongcheng, Taihu, Huaining, Zongyang, and Lujiang counties. The basin extends northeastward, measuring approximately 100 km east-west and no more than 25 km north-south. It is bounded to the northwest by a fault separating it from mountainous terrain composed of metamorphic rocks and filled with Late Cretaceous–Paleocene fluvio-lacustrine deposits dominated by reddish clastic rocks.

In the 1950s, during nationwide geological surveys, Hefei University of Technology conducted the first investigation of Mesozoic and Cenozoic deposits in the Qianshan Basin. In the 1960s, geologists from Geological Survey Team No. 311 of the Bureau of Geology and Mineral Resources of Anhui Province discovered Paleocene vertebrates at Dinghuawu, Xiaoshi, Huaining County in 1966. These fossils were later identified as the turtle *Anhuichelys siaoshihensis* Yeh (1979) and the alligatorid *Eoalligator huiningensis* Young (1982). This discovery attracted researchers from the Institute of Vertebrate Paleontology and Paleoanthropology (IVPP), Chinese Academy of Sciences, Beijing. With assistance from colleagues at Geological Survey Team No. 311, the Qianshan County Museum (formerly the Administrative Office of Cultural Relics of Qianshan County), and more recently the Tianzhushan Global Geopark, IVPP researchers have conducted continuous investigations for nearly half a century since 1970. To date, 61 species (including 9 unnamed) in 45 genera of Paleocene vertebrates have been reported from 42 localities in the Qianshan Basin.

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2 Stratigraphy

Paleocene deposits in the Qianshan Basin were first investigated by Hefei University of Technology in the 1950s, with the first mention of possible Paleogene deposits based on sedimentary rock characteristics. Regional Geological Survey Team No. 311 of the Bureau of Geology of Anhui Province provided the first systematic subdivision of the Paleocene in a 1970 report, later informally published (Chen, 1974). Chen and Xia (1981) formally published a measured section with revisions:

The Wanghudun Section in Qianshan County

Doumu Formation

12. Purplish red, thick matrix-supported conglomerates interbedded with purplish red coarse sandstone, containing fossil vertebrates: *Sinostylops promissus* Tang & Yan, *Archaeolambda tabiensis* Huang, *Heomys orientalis* Li, *Mimotona wana* Li, *Hsiuannania*

13. Purplish red, thick medium-coarse sandstone interbedded with conglom-

erates and shales, containing fossil vertebrates: *Allictops inserrata* Qiu, *Hsiuannania tabiensis* Xu, *Mimotona robusta* Li, *Obtususdon hanhuaensis* Xu, *Agama sinensis* Hou, *Anhuichelys*

Wanghudun Formation

9. Purplish red, thick medium-fine sandstone intercalated with dark purple muddy shales

10. Fresh purplish red, thick fine sandstone intercalated with thin arkose (179.4 m)

11. Grayish purple thin to medium-thick conglomerates and coarse sandstone interbedded with purplish red fine sandstone, rich in fossil vertebrates: *Anictops tabiepedis* Qiu, *Decoredon elongetus* Xu, *Diacronus anhuiensis* Xu, *D. wanghuensis* Xu, *Huaiyangale chianshanensis* Xu, *Harpyodus euros* Chiu & Li, *Mimotona wana* Li, *Mimotona* sp., *Obtusudon hanhuaensis* Xu, *Paranictops majuscula* Qiu, *Pappictidops orientalis* Chiu & Li, *Zeuctherium niteles* Tang & Yan, *Heomys* sp., *Qianshanosaurus huangpuensis* Hou (287 m)

Haixingdi Formation

5. Purplish red, thick medium-fine sandstone interbedded with fine muddy sandstone, intercalated with white arkose and thin conglomerates, containing fossil vertebrates:

6. Fresh purplish red, thick fine sandstone intercalated with grayish white thin feldspar and quartz sandstone, containing fossil vertebrates: *Anictops tabiepedis* Qiu, *Anchilestes* Chiu & Li, *Anaptogale wanghoensis* Xu, *Bemalambda* sp., *Wanogale hodungensis* Xu, *Chianshania gianghuaiensis* Xu, *Anqingosaurus breviocephalus* Hou (418.52 m)

7. Brick red, thick blocky fine sandstone, containing fossil vertebrates: primitive pantodont

——conformity——

Underlying Upper Cretaceous Gaohebu Formation

Qiu et al. (1977) redefined the Wanghudun and Doumu formations based on IVPP field investigations. The Wanghudun Formation, approximately 1800 m thick, overlies the Cretaceous Wanghe Formation and was subdivided into Lower, Middle, and Upper members. The Lower Member consists of purplish red medium-fine sandstone intercalated with conglomerates and grayish white arkose sandstone. The Middle Member comprises mainly interbedded purplish red conglomerates, coarse sandstone, and fine sandstone, with no recorded fossil mammals. The Upper Member is the most fossiliferous unit, comprising purplish and brownish red fine sandstone intercalated with grayish white arkose sandstone. The Doumu Formation disconformably or conformably overlies the Wanghudun Formation and is about 600 m thick. Its Lower Member comprises

thick purplish red medium-fine sandstone intercalated with thin conglomerates and silty mudstone, while the Upper Member consists mainly of interbedded thick conglomerates and sandstone (Qiu et al., 1977). This subdivision has been widely accepted for Paleocene strata in the Qianshan Basin.

The correlation between Chen and Xia' s (1981) and Qiu et al.' s (1977) subdivisions should be noted. The Lower and Middle members of the Wanghudun Formation in Qiu et al.' s scheme roughly correlate with Chen and Xia' s Haixingdi Formation, while the Middle Member corresponds to the upper part of Chen and Xia' s Layer 5. The boundary between the Wanghudun and Doumu formations in Qiu et al.' s scheme lies roughly between layers 8 and 9 in Chen and Xia' s section. Qiu et al. (1977) adopted the Wanghe Formation from unpublished local geological survey data for underlying Late Cretaceous deposits. Later, equivalent deposits were named the Gaohebu Formation based on a new section with better exposures, a name cited in some publications (e.g., Chen and Xia, 1981). We suggest replacing the Wanghe Formation with the Gaohebu Formation.

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3 Localities of Fossil Vertebrates

Paleocene deposits in the Qianshan Basin have produced numerous fossil vertebrates at many localities. Forty-two localities have been recorded in formal publications (Fig. 1 [Figure 1: see original paper]). Based on stratigraphic position, these localities can be grouped into seven fossiliferous horizons recognized in the Qianshan Basin: five in the Wanghudun Formation and two in the Doumu Formation. The localities and their fossil vertebrates are listed below (original locality numbers in brackets):

Figure 1 shows the general location of Anhui Province in China, maps of Anhui showing the location of the Qianshan Basin, and detailed maps of Paleocene vertebrate localities. Open symbols indicate Shanghuan localities, solid symbols Nongshanian localities; triangles and circles denote localities in the Wanghudun and Doumu formations, respectively.

1. Haixingdi (71002); 2. Fanglaowu (71003); 3. Wangdawu (71001); 4. Wanhuawu (71005); 5. Chidoukan (71006); 6. Dingxiawu (70020); 7. Zhangchong; 8. Sanliantang (70023); 9. Zhongjialaowu; 10. Taowu (70022); 11. Yangwu Southwest (71014); 12. Yangwu West (71019); 13. Lijialaowu (70021); 14. Shangxialou (71016); 15. Zhangjiawu Southwest (71010); 16. Zhangjiawu South (71008); 17. Zhangjiawu Southeast (71011); 18. Zhangjiawu East (71009); 19. Zhangxinwu (71007); 20. Wanghudun Northeast; 21. Chenxiawu (71012); 22. Lianhuatang Southeast; 23. Lianhuatang; 24. Fujiashanzui; 25. Xudawu South; 26. Xudawu; 27. Hanhuawu South (71079); 28. Hanhuawu West (71020); 29. Hanxindongwu (71015); 30. Hanjiashanbao; 31. Chongliwu (71018); 32. Zhugongtang West; 33. Meiyuan; 34. Yangxiaowu (71017); 35. Yangxinwu (71071); 36.

Dinghuawu (71080); 37. Chenjiachuanmenkou; 38. Mao' an (71075); 39. Jinshi; 40. Wangjiazha; 41. Huanghetang Reservoir; 42. Yanglaowu

(1) Localities in the basal part of the Lower Member of Wanghudun Formation

Two localities represent the lowest vertebrate-bearing bed in the Qianshan Paleocene.

- Haixingdi (71002): Bemalambdidae gen. et sp. indet., *Qianshanosaurus huangpuensis* Hou, 1974
- Fanglaowu (71003): *Astigale wanensis* Zhang & Tong, 1981, *Benaius qianshuiensis* Wang & Jin, 2004

(2) Localities in the middle part of the Lower Member of Wanghudun Formation

Three localities are included. Wangdawu and Wanhuawu are near the main section, making their inclusion credible. Dinghuahu is farther from the main section but its geographic position and lithologic features suggest correlation with the other two.

- Wangdawu (71001): *Wanogale hodungensis* Xu, 1976, *Chianshania gianghuaiensis* Xu, 1976, *Anaptogale wanghoensis* Xu, 1976, *Anictops tabiepedis* Qiu, 1977, *Anchilestes impolitus* Chiu & Li, 1977, *Plethorodon chienshanensis* Huang & Zheng, 1987, *Bemalambda* sp., *Anqingosaurus brevicephalus* Hou, 1976, *Changjiangosaurus huananensis* Hou, 1976
- Wanhuawu (71005): *Cartictops canina* Ding & Tong, 1979
- Dinghuawu (71080): *Anhuichelys siaoshihensis* Yeh, 1979, *Eoalligator huiningensis* Young, 1982

(3) Localities in the upper part of the Lower Member of Wanghudun Formation

Only one locality with reported fossil vertebrates can be referred to this horizon.

- Chidoukan (71006): *Yantanglestes conexus* (Yan & Tang, 1976), *Bemalambda* sp., *Cartictops canina* Ding & Tong, 1979

(4) Localities in the lower part of the Upper Member of Wanghudun Formation

This is the most fossiliferous horizon in the Qianshan Paleocene. All localities are near the main section, making their inclusion fairly certain.

- Lijialaowu (70021): *Anictops tabiepedis* Qiu, 1977, *A. wanghudunensis* Zheng et al., 1999, *Pappictidops orientalis* Chiu & Li, 1977, *Qianshanosaurus huangpuensis* Hou, 1974, *Qianshanornis rapax* Mayr et al., 2013
- Zhangxinwu (71007): *Anictops tabiepedis* Qiu, 1977
- Wanghudun Northeast: *Paranictops* aff. *P. maiuscula*

- Dingxiawu (70020): *Huaiyangale chianshanensis* Xu, 1976, *Huaiyangale* sp., *Anictops tabiepedis* Qiu, 1977, *Obtususdon hanhuaensis* Xu, 1977
- Zhangjiawu East (71009): *Huaiyangale chianshanensis* Xu, 1976, *Diacronus anhuiensis* Xu, 1976, *Anictops tabiepedis* Qiu, 1977, *Zeuctherium niteles* Tang & Yan, 1976, *Decoredon elongetus* Xu, 1977, *Anhuichelys siaoshihensis* Yeh, 1979
- Zhangjiawu Southeast (71011): *Anictops tabiepedis* Qiu, 1977
- Zhangjiawu South (71008): *Anictops tabiepedis* Qiu, 1977, *Mimotona lii* Dashzeveg & Russell, 1988, *Pappictidops orientalis* Chiu & Li, 1977
- Zhangjiawu Southwest (71010): *Paranictops maiuscula* Qiu, 1977, *Heomys* sp.
- Shangxialou (71016): *Diacronus wanghuensis* Xu, 1976, *Anictops tabiepedis* Qiu, 1977, *Mimotona wana* Li, 1977, *?Altilambda tenuis* Chow & Wang, 1978
- Chenxiawu (71012): *Anictops tabiepedis* Qiu, 1977, *Harpyodus euros* Chiu & Li, 1977
- Zhangchong: *Anhuichelys siaoshihensis* Yeh, 1979
- Yangwu Southwest (71014): *?Paranictops* sp.
- Yangwu West (71019): *Anictops tabiepedis* Qiu, 1977
- Taowu (70022): *Anictops tabiepedis* Qiu, 1977, *Anictops* aff. *A. tabiepedis*, *Paranictops majuscula* Qiu
- Sanliantang (70023): *Wania chowi* Wang, 1995, *Bemalambda* sp. cf. *B. crassa* Chow et al., 1973
- Zhongjialaowu: *Archaeoryctes wangi* Missiaen et al., 2013

(5) Localities in the upper part of the Upper Member of Wanghudun Formation

Eight localities are included. Fujiashanzui, Lianhuatang Southeast, Lianhuatang, and Xudawu South are near the main section and can be referred to this horizon with certainty. Chenjiachuanmenkou, Mao' an, Jinshi, and Wangjiazha are less certain due to their distance from the main section and are included mainly based on biostratigraphic data.

- Fujiashanzui: *Eosigale yujingensis* Hu, 1993, *Mina hui* Li et al., 2016, *Anhuichelys tsienshanensis* Yeh
- Lianhuatang Southeast: *Simplodon qianshanensis* Huang & Zheng, 2003
- Lianhuatang: *Anhuichelys tsienshanensis* Yeh, 1979
- Xudawu South: *Qipania yui* Hu, 1993
- Chenjiachuanmenkou: *Altilambda yujingensis* Wang et al., 1992
- Mao' an (71075): *Altilambda pactus* Chow & Wang, 1978
- Jinshi: *Anhuichelys tsienshanensis* Yeh, 1979
- Wangjiazha: *Anhuichelys tsienshanensis* Yeh, 1979

(6) Localities in the Lower Member of Doumu Formation

The first five localities can be included with certainty as they are near the main section. The last is tentatively included based on lithological features, as the

only reported vertebrate is a calcaneus of Glires that cannot be identified at a lower taxonomic level (Zhang et al., 2016).

- Xudawu: *Anhuichelys tsienshanensis* Yeh, 1979
- Hanhuawu South (71079): *Hsiuannania tabiensis* Xu, 1976, *Allictops inserrata* Qiu, 1977, *Mimotona robusta* Li, 1977, *Obtususdon hanhuaensis* Xu, 1977, *Agama sinensis* Hou, 1974, *Anhuichelys tsienshanensis* Yeh, 1979
- Hanxindongwu (71015): *Allictops inserrata* Qiu, 1977
- Hanhuawu West (71020): *Anhuichelys tsienshanensis* Yeh, 1979
- Hanjiashanbao: *Anhuichelys tsienshanensis* Yeh, 1979
- Huanghetang Reservoir: Glires gen. et sp. indet.

(7) Localities in the Upper Member of Doumu Formation

Among the six localities listed, only Yanglaowu is not near the main section. The lithology, fossil turtle, and geographic location clearly indicate it belongs to this horizon.

- Yangxiaowu (71017): *Hsiuannania* sp., *Heomys orientalis* Li, 1977, *Mimotona wana* Li, 1977, *Hyracolestes ermineus* Matthew & Granger, 1925, *Wanolestes lii* Huang & Zheng, 2002, *Sinostylops promissus* Tang & Yan, 1976, *Archaeolambda tabiensis* Huang, 1977, *Anhuisaurus huainanensis* Hou, 1974, Varaniformes gen. et sp. indet., *Anhuichelys tsienshanensis* Yeh, 1979, *A. doumuensis* Tong et al., 2016
- Chongliwu (71018): *Tinosaurus doumuensis* Hou, 1974
- Yangxinwu (71071): *Anhuichelys doumuensis* Tong et al., 2016
- Zhugongtang West: *Wanshuina lii* Hou, 1994
- Meiyuan: *Anhuichelys doumuensis* Tong et al., 2016
- Yanglaowu: *Anhuichelys doumuensis* Tong et al., 2016

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4 Fossil Vertebrates

Over the past half-century, various fossil vertebrates have been recovered from the aforementioned localities. To date, 52 named species plus 9 unnamed species of reptiles, birds, and mammals have been reported from the Paleocene of the Qianshan Basin. A complete faunal list is provided in Appendix 1.

4.1 Reptilia

Reptilian fossils from the Qianshan Paleocene represent three major groups: Testudines, Squamata, and Crocodilia.

4.1.1 Testudines Fossil turtles are relatively common, found in many localities (see Tong et al., 2016 for details). All specimens were referred to the single genus *Anhuichelys* Yeh, 1979. When Yeh (1979) first reported the basin'

s fossil turtles, he assigned *Anhuichelys* to Emydidae, with two new species (*A. siaoshihensis* and *A. tsienshanensis*) and an unnamed species, *Anhuichelys* sp. Subsequent specimens were collected by Qianshan County Museum colleagues, but little further research was conducted except for Chen (1983), who described *A. xinzhouensis* from the Xinzhou Basin, Hubei Province.

Recently, Tong et al. (2016) comprehensively studied all available Paleocene turtle specimens from both the Qianshan and Xinzhou basins. In addition to referring new specimens to *A. siaoshihensis* and *A. tsienshanensis*, they synonymized *A. xinzhouensis* with *A. tsienshanensis* and named a new species, *A. doumuensis*, using Yeh' s *Anhuichelys* sp. as the holotype. They also described four specimens as an unnamed species, *Anhuichelys* sp. Phylogenetic analysis suggests *Anhuichelys* is a member of the stem Testudinidae. According to Tong et al. (2016), "*Anhuichelys* is likely a land turtle and also the first testudinoid to develop the hinge on the shell."

Stratigraphically, *Anhuichelys siaoshihensis* occurs in the Lower Member and lower part of the Upper Member of the Wanghudun Formation; *A. tsienshanensis* occurs from the upper part of the Upper Member of the Wanghudun Formation through the Upper Member of the Doumu Formation; *A. doumuensis* occurs only in the Upper Member of the Doumu Formation; and *Anhuichelys* sp. occurs in the upper part of the Upper Member of the Wanghudun Formation and possibly the Lower Member of the Doumu Formation. The occurrence of fossil turtles shows clear biostratigraphic significance: *A. siaoshihensis* is a member of the Shanghuan ALMA (Early Paleocene), correlative with the Puercan and Torrejonian NALMA. The other three species are members of the Nongshanian ALMA (Middle Paleocene), correlative with the early–middle Tiffanian NALMA.

4.1.2 Squamata Hou (1974) first reported fossil lizards from the Qianshan Paleocene, naming two new genera and four new species: *Qianshanosaurus huangpuensis*, *Anhuisaurus huainanensis*, *Tinosaurus doumuensis*, and *Agama sinensis*, referring *Q. huangpuensis* to Iguanidae and the others to Agamidae. Two years later, Hou (1976) described *Anqingosaurus brevicephalus* and *Changjiangosaurus huananensis*, referring them to Chamaeleontidae and Changjiangosauridae respectively.

The systematic position of these lizard taxa has long been debated (see Dong et al., 2016 for details). Dong et al. (2016) reexamined all reported lizard specimens and revised their taxonomic positions under the current classification of Squamata. They referred *Agama sinensis* (nomen dubium), *Qianshanosaurus huangpuensis*, and *Tinosaurus doumuensis* to Acrodonta, and considered *Anhuisaurus huainanensis*, *Anqingosaurus brevicephalus*, and *Changjiangosaurus huananensis* as Squamata *incertae sedis*. They also recognized the first varaniform from the Qianshan Paleocene, represented by a nearly complete right dentary, six articulated vertebrae, and a sacrum with the last presacral, originally identified as *Anhuisaurus huainanensis* (Hou, 1974).

Stratigraphically, *Anqingosaurus brevicephalus* and *Changjiangosaurus huananensis* were collected from the Lower Member of the Wanghudun Formation, and *Qianshanosaurus huangpuensis* from both the Lower Member and lower part of the Upper Member, representing Early Paleocene Shanghuan squamates. *Agama sinensis* was reported only from the Lower Member of the Doumu Formation (recorded as Wanghudun Formation by mistake in Hou, 1974:199). *Tinosaurus doumuensis*, *Anhuisaurus huainanensis*, and Varaniformes gen. et sp. indet. were all from the Upper Member of the Doumu Formation, representing Middle Paleocene Nongshanian squamates. See Dong et al. (2016) for detailed locality information.

4.1.3 Crocodilia The first crocodilian fossil from the Qianshan Paleocene was found by the geological survey team at Dinghuawu, Huaining County in 1966 (RGSBGA, 1988b). Young (1982) formally described it as *Eoalligator huiningensis*, originally referred to Alligatorinae (Young, 1982), though this placement was later questioned (Whiting and Hastings, 2015). We follow Young (1982) pending restudy.

Another crocodilian, *Wanosuchus atresus*, was reported by Zhang (1981) from possibly the Paleocene of the Qianshan Basin, placed within its own family Wanosuchidae.

Eoalligator huiningensis came from the Lower Member of the Wanghudun Formation at Dinghuawu (Qiu et al., 1977), representing the Early Paleocene Shanghuan. The locality and horizon of *Wanosuchus atresus* remain unknown.

4.2 Aves

Two fossil birds have been reported from the Qianshan Paleocene. *Wanshuina lii* was represented by a right humerus shaft, distal left tibiotarsus, and associated left tarsometatarsus lacking the distal end, originally referred to Rallidae (Hou, 1994). It was later considered similar to *Walbeckornis* from the Paleocene of Germany (Mayr, 2009; Mayr et al., 2013). Pending further examination, we tentatively follow Hou (1994) in listing *W. lii* as Rallidae.

The other fossil bird, *Qianshanornis rapax*, was considered similar to *Strigogyps* and assigned to its own family Qianshanornithidae (Mayr et al., 2013).

Wanshuina lii was collected from the Upper Member of the Doumu Formation at Zhugongtang West (Nongshanian ALMA). *Qianshanornis rapax* specimens were found in the lower part of the Upper Member of the Wanghudun Formation at Lijialaowu (Shanghuan ALMA).

4.3 Mammalia

Fossil mammals are relatively common and highly diverse in the Qianshan Paleocene deposits. Twenty-eight localities have yielded fossil mammals, forming

the Qianshan Paleocene mammal fauna comprising 39 named species plus eight indeterminate ones.

4.3.1 Anagalida Anagalida, an Asian endemic mammalian group, shows the most diverse record among Paleocene mammals in the Qianshan Basin, with three families: Anagalidae, Pseudictopidae, and Astigalidae.

Anagalidae: Xu (1976) first reported Qianshan Paleocene anagalids, describing seven species and two unnamed taxa across six genera: *Huaiyangale chianshanensis*, *Huaiyangale* sp., *Hsiuannania tabiensis*, *Hsiuannania* sp., *Wanogale hodungensis*, *Chianshania gianghuaiensis*, *Diacronus wanghuensis*, *D. anhuiensis*, and *Anaptogale wanghoensis*. He assigned *Huaiyangale* and *Hsiuannania* to Anagalidae and tentatively referred the other four genera to the same family.

Hu (1993) reported two new genera and species, *Eosigale gujingensis* and *Qipania yui*, based on the best-preserved anagalid material from the Qianshan Basin. Phylogenetic analysis confirmed the attribution to Anagalidae of *Huaiyangale*, *Eosigale*, *Qipania*, and *Hsiuannania*, tentatively referred *Diacronus* and *Anaptogale* to the family, assigned *Chianshania* to Astigalidae, and considered *Wanogale* as family indet.

Szalay and Li (1986) combined *Diacronus anhuiensis* Xu (1976) with *Decoredon elongetus* Xu (1977) into *Decoredon anhuiensis*, proposing it as "the oldest recognized member of euprimates, either an omomyid or a member of the common stock which gave rise to Adapidae and Omomyidae" (Szalay and Li, 1986:387). This assignment received little support (Rose, 1994) and was considered questionable (Rose et al., 1994) or unlikely (Gingerich et al., 1991). Due to suspect conspecific assignment of the holotypes (Rose et al., 1994), they are better considered separate species, with *Diacronus anhuiensis* tentatively assigned to Anagalidae.

Anaptogale and *Wanogale* were collected from the Lower Member of the Wanghudun Formation, while *Huaiyangale* and *Diacronus* came from the lower part of the Upper Member, making these four genera members of the Early Paleocene Shanghuan ALMA. *Eosigale* and *Qipania* were found in the upper part of the Upper Member of the Wanghudun Formation, and *Hsiuannania* from the Doumu Formation, representing anagalids of the Middle Paleocene Nongshanian ALMA. See Xu (1976) and Hu (1993) for locality information.

Pseudictopidae: Qiu (1977) conducted a comprehensive study of pseudictopids, describing three new species across three new genera plus one unnamed and one *affinis* species: *Anictops tabiepedis*, *Anictops* aff. *A. tabiepedis*, *Paranictops majuscule*, *Paranictops* sp., and *Allictops inserrata*. Ding and Tong (1979) named *Cartictops canina* based on an anterior left lower jaw portion (IVPP V 4307) previously referred to *Paranictops* sp. by Qiu (1977) and a left m2 or m1 (IVPP V 4318) described as indeterminate by Chiu and Li (1977). Zheng et al. (1999) reported new specimens, naming *Anictops wanghudunensis* and referring others to *Anictops tabiepedis* and *Paranictops* aff. *P. majuscule*.

Cartictops and *Paranictops* were collected from the Lower Member and lower part of the Upper Member of the Wanghudun Formation respectively, while *Anictops* occurs in both horizons, representing Early Paleocene Shanghuan pseudictopids. *Allictops*, from the Lower Member of the Doumu Formation, represents the only pseudictopid form of the Middle Paleocene Nongshanian ALMA in the Qianshan Basin.

Astigalidae: Two astigalid species have been reported from the Qianshan Paleocene. *Astigale wanensis* was named by Zhang and Tong (1981) based on a right lower jaw from Fanglaowu. *Chianshania gianghuaiensis*, collected at Wangdawu and originally assigned to Anagalidae (Xu, 1976), was later considered an astigalid (Hu, 1993). Both taxa came from the Lower Member of the Wanghudun Formation and are of Early Paleocene Shanghuan age.

4.3.2 Simplicidentata Simplicidentata from the Qianshan Basin are represented by eurymylids. Li (1977) first reported *Heomys orientalis*, identifying it as a remote ancestor of rodents based on similarities to primitive rodents. This interpretation gained support from further examinations (Dawson et al., 1984; Li et al., 1987; Li and Ting, 1985, 1993; Li and Chow, 1994) and studies on related forms (Meng and Wyss, 1994, 2001; Meng et al., 1994b, 2003). Some researchers considered *Heomys* a primitive rodent (Flynn, 1994; McKenna and Bell, 1997), but recent phylogenetic analyses do not support a closer relationship to typical rodents than other eurymylids (Meng and Wyss, 2001; Meng et al., 2003; Meng, 2004). Currently, *Heomys* is best assigned to Eurymylidae. Li (1977) also identified a poorly preserved anterior skull portion as *Heomys* sp.

Heomys orientalis was collected from the Upper Member of the Doumu Formation at Yangxiaowu (Li, 1977), representing the Middle Paleocene Nongshanian ALMA. *Heomys* sp. was found in the lower part of the Upper Member of the Wanghudun Formation at Zhangjiawu Southwest, representing a eurymylid record in the Early Paleocene Shanghuan ALMA.

4.3.3 Mimotonida Mimotonida was proposed by Li et al. (1987) to include basal Glires with two pairs of incisors in both upper and lower dentitions. Although recent phylogenetic analyses show Mimotonida to be paraphyletic (Meng and Wyss, 2001; Meng, 2004; Asher et al., 2005), the term remains convenient until better phylogenetic resolution of basal Glires is available (Li et al., 2016). Two mimotonidan genera, *Mimotona* and *Mina*, have been reported from the Qianshan Basin, representing families Mimotonidae and Mimolagidae respectively (Li, 1977; Li et al., 2016).

Mimotonidae: Li (1977) proposed Mimotonidae to include only the type genus *Mimotona*, though several genera were later referred to it (see Li et al., 2016). Accumulating data suggest Mimotonidae is monophyletic and contains only *Mimotona* (Li et al., 2016).

Li (1977) initially described two named and one unnamed *Mimotona* species

from the Qianshan Paleocene: *M. wana*, *M. robusta*, and *Mimotona* sp. He noted differences in *Mimotona* sp. that might indicate a new species, which Dashzeveg and Russell (1988) later named *M. lii*.

The holotype and two referred left lower molars of *Mimotona wana* came from the Upper Member of the Doumu Formation at Yangxiaowu (Li, 1977). The type and only specimen of *M. robusta* was from the Lower Member of the Doumu Formation at Hanhuawu South. Both are Nongshanian ALMA (Middle Paleocene) in age. The type and only specimen of *M. lii* was collected from the lower part of the Upper Member of the Wanghudun Formation at Zhangjiawu South (Early Paleocene Shanghuan ALMA). A right premaxilla with alveoli for I2-3 (IVPP V 4326) from the lower part of the Upper Member of the Wanghudun Formation at Shangxialou was referred to *M. wana* as a paratype (Li, 1977), but the recent discovery of *Mina hui* (Li et al., 2016) raises doubts about this assignment, requiring further evidence for *M. wana* in the Early Paleocene.

Mimolagidae: Mimolagidae is represented in the Qianshan Basin by the recently reported basal duplicidentate *Mina hui*. The type specimens from the upper part of the Upper Member of the Wanghudun Formation at Fujiashanzui include a partial right rostrum with dI2 and I3 and a fragmentary left maxilla with M1, M2 and alveoli of P2-4 (IVPP V 7509) (Li et al., 2016). It is a member of the Middle Paleocene Nongshanian ALMA.

4.3.4 Mesonychia Mesonychia is represented by a single mesonychid species in the Qianshan Basin. Yan and Tang (1976) reported *Lestes conexus* from the Qianshan Paleocene. The genus name was later replaced with *Yantanglestes* because *Lestes* was preoccupied by a zygopteran insect (Ideker and Yan, 1980). *Yantanglestes conexus* was collected from the Lower Member of the Wanghudun Formation at Chidoukan (originally called 150 meters northwest of Jiangjiawu) (Yan and Tang, 1976; Qiu et al., 1977), assigning it to the Early Paleocene Shanghuan ALMA.

4.3.5 Pantodonta Pantodonta is one of the most common mammalian groups in the Chinese Paleocene. Four families are recorded in the Qianshan Basin: Bemalambdidae, Harpyodidae, Pantolambdodontidae, and Pastoralodontidae, all Asian endemics.

Bemalambdidae: Compared to contemporaneous Nanxiong and Chijiang basins, Qianshan Bemalambdidae specimens are fewer and poorly preserved. The reported taxa, *Bemalambda* sp. and Bemalambdidae gen. et sp. indet., are represented by fragmentary material that cannot be further identified (Huang, 1978). Both came from the Lower Member of the Wanghudun Formation. *Bemalambda* sp. specimens from Chidoukan and Wangdawu are stratigraphically higher than Bemalambdidae gen. et sp. indet. from Haixingdi. Both taxa are Early Paleocene Shanghuan in age.

Harpyodidae: Chiu and Li (1977) named *Harpyodus euros* based on a frag-

mentary left maxilla with M1–3, referring it to an indeterminate family of Deltatheridia. Wang (1979) established Harpyodidae for the genus and suggested pantodont affinities when describing a new *Harpyodus* species from the upper Lannikeng Member of the Chijiang Formation in Jiangxi. This pantodont assignment has been widely accepted (e.g., de Muizon and Marshall, 1992; McKenna and Bell, 1997; Wang et al., 1998; de Muizon et al., 2015). *Harpyodus euros* was found in the lower part of the Upper Member of the Wanghudun Formation at Chenxiawu (Chiu and Li, 1977), within the Early Paleocene Shanghuan ALMA.

Pantolambdodontidae: The only pantolambdodontid from the Qianshan Basin is *Archaeolambda tabiensis*, reported by Huang (1977) based on a nearly complete skeleton—the only known skeleton of the genus and family. Huang (1977) referred *A. tabiensis* to Archaeolambdidae but noted possible synonymy with Pantolambdodontidae. Chow and Qi (1978) argued that *Pantolambdodon* and *Archaeolambda* belong to one family and that previous Archaeolambdidae taxa should be reassigned to Pantolambdodontidae, an opinion accepted by subsequent researchers (e.g., Huang, 1995; Huang and Chen, 1997; Huang and Zheng, 1997, 2003b; McKenna and Bell, 1997; Tong and Wang, 2006). The *A. tabiensis* specimen was collected from the Upper Member of the Doumu Formation at Yangxiaowu (Huang, 1977), representing the Middle Paleocene Nongshanian ALMA.

Pastoralodontidae: Pastoralodontids are the most common pantodonts in the Qianshan Paleocene, represented by three species of one genus: *Altilambda pactus*, *A. tenuis*, and *A. yujingensis* (Chow and Wang, 1978; Wang et al., 1992). The *A. tenuis* specimens (two fragmentary lower jaws) are poorly preserved, making their assignment to *Altilambda* questionable. All three species came from the Upper Member of the Wanghudun Formation. *?A. tenuis* from the lower part of the Upper Member at Shangxialou (Chow and Wang, 1978) is an Early Paleocene Shanghuan mammal. The other two species, from Mao'an and Chenjiachuanmenkou, are morphologically more derived and possibly stratigraphically higher, likely representing the Middle Paleocene Nongshanian ALMA.

4.3.6 Tillodontia Three mammalian genera and species from the Qianshan Basin are referable to Tillodontia (Wang and Jin, 2004). *Plethorodon chienshanensis* was described by Huang and Zheng (1987) based on a partial skull with complete bilateral cheek tooth dentition, tentatively assigned to Pantodonta under family Plethorodontidae. De Muizon and Marshall (1992) considered it a tillodont rather than pantodont, an opinion followed by McKenna and Bell (1997) and Wang et al. (1998) but disputed by Ting (1998) and Tong et al. (2003). Detailed comparison and phylogenetic analysis by Wang and Jin (2004) confirmed its tillodont status.

Huang and Zheng (2003a) named another tillodont, *Simplodon qianshanensis*, based on a right maxilla with P3–M3, questionably referring it to Esthonychidae.

Simplodon shows some tillodont similarities, but insufficient evidence supports its Esthonychidae assignment; it may be more reasonably referred to Tillodontia family indet.

Wang and Jin (2004) described a left lower jaw with c–m3 from the Qianshan Paleocene, naming it *Benaius qianshuiensis* and classifying it as a tillodont without family assignment.

Plethorodon chienshanensis and *Benaius qianshuiensis* were collected from the Lower Member of the Wanghudun Formation at Wangdawu and Fanglaowu respectively (Huang and Zheng, 1987; Wang and Jin, 2004). Wangdawu is stratigraphically higher than Fanglaowu, but both are Early Paleocene Shanghuan. *Simplodon qianshanensis* was found in the upper part of the Upper Member of the Wanghudun Formation southeast of Lianhuatang (Huang and Zheng, 2003a), representing the Middle Paleocene Nongshanian.

4.3.7 Arctostylopida Arctostylopida contains only one family, Arctostylopidae (Cifelli and Schaff, 1998). Fossil arctostylopids were originally thought related to South American notoungulates (Matthew, 1915) and were referred to Notoungulata for many years (Schlosser, 1923; Matthew and Granger, 1925; Matthew et al., 1929; Patterson, 1934; Tang and Yan, 1976; Chow and Qi, 1978; Zheng, 1979; Rose, 1981; Gingerich, 1985; Zheng and Huang, 1986; Nessov, 1987). Cifelli et al. (1989) considered Arctostylopidae unrelated to Notoungulata and established the new order Arctostylopida, an opinion widely accepted (e.g., McKenna and Bell, 1997; Huang and Zheng, 1997, 2003b; Huang et al., 2001; Kondrashov and Lucas, 2004a; Zack, 2004; Tong and Wang, 2006; Missiaen and Smith, 2008; Secord, 2008; Wang et al., 2008; Missiaen et al., 2012).

Only one arctostylopid species, *Sinostylops promissus*, has been reported from the Upper Member of the Doumu Formation at Yangxiaowu (Tang and Yan, 1976), representing the Middle Paleocene Nongshanian ALMA.

4.3.8 Carnivora The only carnivoran species, *Pappictidops orientalis*, was described by Chiu and Li (1977) based on a right maxilla with canine and P2–M2 (holotype) and a juvenile left lower jaw horizontal ramus (referred specimen). *Pappictidops* was originally referred to Viverravinae of Miacidae (Chiu and Li, 1977), considered most similar to North American Paleocene *Ictidopappus* (Chiu and Li, 1977; Wang, 1978). Flynn and Galiano (1982) resurrected family Viverravidae, which has been widely used (e.g., Eaton, 1985; Gingerich and Winkler, 1985; Gingerich, 1989; Gunnell et al., 1992; Polly, 1997; Gunnell, 1998; Eberle and McKenna, 2002; Meehan and Wilson, 2002; Huang and Zheng, 2005; Gingerich and Smith, 2006; Tong and Wang, 2006; Beard and Dawson, 2009; Friscia and Rassmussen, 2010; Scott et al., 2013). It is reliable to assign *Pappictidops* and *Ictidopappus* to Viverravidae. Some papers mention Asian viverravid *Pappictidops* in the Late Paleocene and earliest Eocene (Gingerich and Winkler, 1985; Polly, 1997), but the genus is known only from the Paleocene of the Qianshan and Nanxiong basins (Chiu and Li, 1977; Wang, 1978).

Qianshan *Pappictidops* specimens were discovered in the lower part of the Upper Member of the Wanghudun Formation at Zhangjiawu and Lijialaowu (Chiu and Li, 1977), representing the Early Paleocene Shanghuan ALMA.

4.3.9 Cimolesta Chiu and Li (1977) described a fragmentary right lower jaw with p3–m1 as *Hyracolestes ermineus* under Deltatheridia. *H. ermineus* was first named from the Paleocene of Mongolia and questionably referred to Creodonta (Matthew and Granger, 1925). Van Valen (1966) placed it in Erinaceoidea of Insectivora, while Szalay and McKenna (1971) referred it to Deltatheridiidae of Insectivora. McKenna et al. (1984) moved *H. ermineus* to Micropternodontidae of Soricomorpha. Currently, *Hyracolestes* is included in Sarcodontidae of the mirorder Cimolesta (Lopatin and Kondrashov, 2004; Missiaen and Smith, 2008). The species was found in the Upper Member of the Doumu Formation at Yangxiaowu (Middle Paleocene Nongshanian ALMA).

4.3.10 Didymoconida The taxonomic position of Didymoconidae varies greatly, having been placed in Insectivora (Meng et al., 1994a; Wang et al., 2001), Deltatheridia (Mellett and Szalay, 1968; Tang and Yan, 1976), Leptictida, Mesonychia (Lopatin, 1997), Condylarthra (Gingerich, 1981), Didymoconida (Lopatin, 2001; Morlo and Nagel, 2007), and Order indet. (Li et al., 1979; Meng, 1990). We tentatively use Didymoconida as the higher-level taxon.

Tang and Yan (1976) reported *Zeuctherium niteles* as a didymoconid based on a partial skull. Missiaen et al. (2013) described *Archaeoryctes wangi* based on a pair of lower jaws. Huang and Zheng (2002) named *Wanolestes lii* based on incomplete lower jaws and referred it to ?Micropternodontidae of Soricomorpha. Lopatin (2006) considered *Wanolestes* similar to *Archaeoryctes* and placed it in Didymoconidae.

Zeuctherium and *Archaeoryctes wangi* were found in the lower part of the Upper Member of the Wanghudun Formation at Zhangjiawu East and Zhongjialaowu respectively, representing the Early Paleocene Shanghuan ALMA. *Wanolestes lii* specimens came from the Upper Member of the Doumu Formation at Yangxiaowu (Middle Paleocene Nongshanian ALMA).

4.3.11 Order indet. Several mammal species named from Qianshan Paleocene materials cannot be assigned to higher taxonomic groups with certainty.

Anchilestes impolitus was named by Chiu and Li (1977) based on incomplete left upper and lower jaws with P3–M2 and p4–m3 from one individual, originally referred to Zalambdalestidae within Anagalida. Ting and Zheng (1989) reevaluated its affinity, assigning it to Tillodontia. However, the morphology of both upper and lower dentitions is distinct from tillodonts and zalambdalestids, providing little evidence for special relationship to either group (Wang et al., 1998; Wang and Jin, 2004). *Anchilestes impolitus* was found in the Lower Mem-

ber of the Wanghudun Formation at Wangdawu (Early Paleocene Shanghuan ALMA).

Decoredon elongetus was described based on left and right lower jaws with p4–m3, originally referred to Hyopsodontidae within Condylarthra (Xu, 1977). Szalay and Li (1986) combined *Decoredon elongetus* with *Diacronus anhuiensis* into *Decoredon anhuiensis*, considering it a member of ?Omomyidae within Euprimates and naming new subfamily Decoredontinae. This assignment received little support and was considered questionable (Rose, 1994; Rose et al., 1994) or unlikely (Gingerich et al., 1991). Kondrashov and Lucas (2004b) considered *Decoredon anhuiensis* lacking features typical of archaic ungulates or omomyid primates but accepted the synonymy. As noted, suspect conspecific assignment of the holotypes (Rose et al., 1994) suggests treating them as separate species, leaving *Decoredon elongetus* as Order and Family *incertae sedis*. Specimens were collected from the lower part of the Upper Member of the Wanghudun Formation at Zhangjiawu East (Xu, 1977), indicating Early Paleocene Shanghuan occurrence.

Obtususdon hanhuaensis was described by Xu (1977) based on a fragmentary right lower jaw with p4–m3 (holotype) and a fragmentary left lower jaw with p4–m3. Its taxonomic position is indeterminate pending better specimens. The holotype was collected from the Lower Member of the Doumu Formation at Hanhuawu South (Middle Paleocene Nongshanian ALMA). The referred specimen came from the lower part of the Upper Member of the Wanghudun Formation at Dingxiawu (Early Paleocene Shanghuan ALMA).

Wania chowi was based on two left maxilla fragments and a pair of lower jaws from one individual (Wang, 1995), originally referred to Zhelestidae in Mixotheridia. Nessov et al. (1998) argued *Wania chowi* "is not a zhelestid but may have anagalidan affinities." As phylogenetic position determination requires further study, *Wania chowi* is temporarily classified as Order and Family indeterminate (Wang et al., 1998). Specimens were collected from the lower part of the Upper Member of the Wanghudun Formation (Early Paleocene Shanghuan ALMA).

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5 Correlation and Age Determination

Among Chinese Paleocene basins, the Nanxiong, Qianshan, Chijiang, and Erlian (Nei Mongol) basins have yielded particularly important mammal records. The first three mainly produce Early–Middle Paleocene mammals, while the Erlian Basin documents later Paleocene faunas. These records provide a baseline for correlating Chinese mammal-bearing Paleocene strata. Previous researchers proposed Paleocene correlations within China, considering the Shanghu, Shizikou, and Wanghudun formations and their correlatives as Early–Middle Paleocene, and the Nongshan, Chijiang, Doumu, and Nomogen (Erlian Basin) formations and their correlatives as Late Paleocene (South China "Red Beds" Research

Group, 1977; Zheng and Qiu, 1979; Chow and Zheng, 1980; Li and Ting, 1983; Russell and Zhai, 1987).

Li and Ting (1983) proposed two provincial mammal ages, Shanghuan and Nongshanian, for Early–Middle and Late Paleocene respectively, tentatively correlating Shanghuan with North American Puercan and Torrejonian and Nongshanian (including present Gashatan) with Tiffanian. Sloan (1987) followed the two-age scheme but favored Gashatan over Nongshanian for the Asian Late Paleocene based on priority, correlating Shanghuan with Torrejonian and part of Tiffanian (To1–Ti4), and Gashatan (=Nongshanian of Li and Ting, 1983) with late Tiffanian–Clarkforkian (Ti5–Cf3). Tong et al. (1995) continued using Shanghuan and Nongshanian (including some Gashatan correlatives) as Early and Late Paleocene provincial mammal ages, correlating Shanghuan with Puercan and early–middle Torrejonian, and Nongshanian with late Torrejonian through Clarkforkian. Lucas and Williamson (1995) proposed correlating Shanghuan with Puercan based on evolutionary stages of certain taxa, but Wang et al. (1998) disagreed. Both Wang et al. (1998) and Ting (1998) used three ages —Shanghuan, Nongshanian, and Gashatan—with slightly different North American correlations. Ting (1998) correlated them with Torrejonian, Tiffanian, and Clarkforkian respectively, while Wang et al. (1998) considered them correlative with Puercan through middle Torrejonian (Pu1–To2), late Torrejonian through middle Tiffanian (To3–Ti4), and late Tiffanian through Clarkforkian (Ti5–Cf3).

Recent paleomagnetic results from the Nanxiong Basin indicate the boundary between the Shanghu Formation and underlying Pingling Formation lies within the upper half of Chron C29R, consistent with other precisely constrained K/Pg boundaries worldwide (Clyde et al., 2010). Paleomagnetic results from the Chijiang and Nanxiong basins clearly show the Shanghuan is Early Paleocene (Danian), corresponding to North American Puercan and Torrejonian. Placement of the Shanghuan/Nongshanian boundary near the top of Chron C27N implies synchroneity with the Torrejonian/Tiffanian boundary (Clyde et al., 2008; 2010). Combined with Erlian Basin results (Sun et al., 2009), the Nongshanian/Gashatan boundary lies between the upper part of Chron C26R and Chron C26N, corresponding to the upper part of the Tiffanian. Therefore, Shanghuan and Nongshanian probably correlate with the Early Paleocene Danian and Middle Paleocene Selandian of the Global Geologic Time Scale (Vandenberghe et al., 2012), indicating that the Wanghudun and Doumu formations and their fossil vertebrates are Early and Middle Paleocene in age.

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6 Concluding Remarks

The Mesozoic and Cenozoic redbeds in the Qianshan Basin consist of a set of monocline clastic rocks subdivided into the Late Cretaceous Gaohebu Formation and the Paleocene Wanghudun and Doumu formations. The Wanghudun Formation is further subdivided into Lower, Middle, and Upper members, while

the Doumu Formation comprises Lower and Upper members.

Continuous investigations have yielded numerous vertebrate specimens. Sixty-one species (including 9 unnamed) in 45 genera of vertebrates—representing reptiles, birds, and mammals—have been reported from the Paleocene of the Qianshan Basin. Mammals are most diverse, with 46 species (7 unnamed) in 33 genera representing 16 families in 10 orders. Based on stratigraphic distribution, seven fossiliferous horizons can be recognized: (1) basal part of the Lower Member of Wanghudun Formation; (2) middle part of the Lower Member of Wanghudun Formation; (3) upper part of the Lower Member of Wanghudun Formation; (4) lower part of the Upper Member of Wanghudun Formation; (5) upper part of the Upper Member of Wanghudun Formation; (6) Lower Member of Doumu Formation; and (7) Upper Member of Doumu Formation.

Mammalian biostratigraphic evidence indicates that strata from the Lower Member through the lower part of the Upper Member of the Wanghudun Formation correlate roughly with the Shanghu Formation of the Nanxiong Basin and the Shizikou Formation of the Chijiang Basin (Shanghuan ALMA). The upper part of the Upper Member of the Wanghudun Formation and the Doumu Formation correlate with the Nongshan Formation of the Nanxiong Basin and the Chijiang Formation of the Chijiang Basin (Nongshanian ALMA). Paleomagnetic results from the Chijiang and Nanxiong basins suggest Shanghuan correlates with Puercan and Torrejonian NALMA, while Nongshanian correlates with early to middle Tiffanian (Ti1–4a). Shanghuan and Nongshanian probably correspond to the Early Paleocene Danian and Middle Paleocene Selandian of the Global Geologic Time Scale.

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Appendix 1: Faunal List of Paleocene Vertebrates in the Qianshan Basin

(In the bracket behind the taxa, 1.1 refers to the Lower Member of the Wanghudun Formation, 1.3a refers to the lower part of the Upper Member of the Wanghudun Formation, 1.3b refers to the upper part of the Upper Member of the Wanghudun Formation, 2.1 refers to the Lower Member of Doumu Formation, and 2.2 refers to the Upper Member of the Doumu Formation.)

Reptilia Laurenti, 1768
Testudines Linnaeus, 1758
Cryptodira Cope, 1868
Testudinoidea Batsch, 1788
Anhuichelys Yeh, 1979
- *A. siaoshihensis* Yeh, 1979 (1.1, 1.3a)
- *A. tsienshanensis* Yeh, 1979 (1.3b, 2.1, 2.2)
- *A. doumuensis* Tong, Li, Li, Chen, Li, Yu, Yu, Cheng, Di & Claude, 2016 (2.2)
- *Anhuichelys* sp. (1.3b, 2.1?)

Squamata Oppel, 1811
Iguania Cope, 1864
Acrodonta Cope, 1864
- *Agama sinensis* Hou, 1974 (nomen dubium) (2.1)
- *Anhuisaurus huainanensis* Hou, 1974 (2.2)
- *Qianshanosaurus huangpuensis* Hou, 1974 (1.1, 1.3a)
- *Tinosaurus doumuensis* Hou, 1974 (2.2)

Anguimorpha Fürbringer, 1900
Varaniformes Conrad, 2008
- Gen. et sp. indet. (2.2)

Squamata incertae sedis
- *Anqingosaurus brevicephalus* Hou, 1976 (1.1)
- *Changjiangosaurus huananensis* Hou, 1976 (1.1)

Crocodilia Gmelin, 1788
Wanosuchidae Zhang, 1981
- *Wanosuchus atresus* Zhang, 1981 (1.3?)

Alligatoridae Gray, 1844
Alligatorinae Gray, 1844
- *Eoalligator huiningensis* Young, 1982 (1.1)

Aves Linnaeus, 1758
Gruiformes Coues, 1884
Rallidae Vigors, 1825
- *Wanshuina lii* Hou, 1994 (2.2)

Order indet.
Qianshanornithidae Mayr, Yang, De Bast, Li & Smith, 2013
- *Qianshanornis rapax* Mayr, Yang, De Bast, Li & Smith, 2013 (1.3a)

Mammalia Linnaeus, 1758
Anagalida Szalay & McKenna, 1971
Anagalidae Simpson, 1931
- *Huaiyangale chianshanensis* Xu, 1976 (1.3a)
- *Huaiyangale* sp. (1.3a)
- *Hsiuannania tabiensis* Xu, 1976 (2.1)
- *Hsiuannania* sp. (2.2)
- *Eosigale gujingensis* Hu, 1993 (1.3b)
- *Qipania yui* Hu, 1993 (1.3b)

?Anagalidae Simpson, 1931
- *Diacronus wanghuensis* Xu, 1976 (1.3a)
- *Diacronus anhuiensis* Xu, 1976 (1.3a)
- *Anaptogale wanghoensis* Xu, 1976 (1.1)

Pseudictopidae Sulimski, 1968
- *Anictops tabiepedis* Qiu, 1977 (1.1, 1.3a)
- *Anictops* aff. *A. tabiepedis* Qiu, 1977 (1.3a)
- *Anictops wanghudunensis* Zheng, Zheng & Huang, 1999 (1.3a)
- *Paranictops majuscula* Qiu, 1977 (1.3a)
- *Paranictops* aff. *P. majuscule* Qiu, 1977 (1.3a)
- *Paranictops* sp. (1.1)
- *Allictops inserrata* Qiu, 1977 (2.1)
- *Cartictops canina* Ding & Tong, 1979 (1.1)

Astigalidae Zhang & Tong, 1981
- *Astigale wanensis* Zhang & Tong, 1981 (1.1)
- *Chianshania gianghuaiensis* Xu, 1976 (1.1)

Family indet.
- *Wanogale hodungensis* Xu, 1976 (1.1)

Simplicidentata Weber, 1904
Eurymylidae Matthew, Granger & Simpson, 1929
- *Heomys orientalis* Li, 1977 (2.2)
- *Heomys* sp. (1.3a)

Duplicidentata Illiger, 1811
Mimotonida Li, Wilson, Dawson & Krishtalka, 1987
Mimotonidae Li, 1977
- *Mimotona wana* Li, 1977 (2.2)
- *Mimotona robusta* Li, 1977 (2.1)
- *Mimotona lii* Dashzeveg & Russell, 1988 (1.3a)

Mimolagidae Szalay, 1985
- *Mina hui* Li, Wang, Zhang, Mao & Meng, 2016 (1.3b)

Didymoconida Lopatin, 2001
Didymoconidae Kretzoi, 1943
- *Zeuctherium niteles* Tang & Yan, 1976 (1.3a)
- *Archaeoryctes wangi* Missiaen, Solé, De Bast, Yan, Li & Smith, 2013 (1.3a)
- *Wanolestes lii* Huang & Zheng, 2002 (2.2)

Carnivora Bowdich, 1821
Viverravidae Wortman & Matthew, 1899
- *Pappictidops orientalis* Chiu & Li, 1977 (1.3a)

Mesonychia Matthew, 1937
Mesonychidae Cope, 1875
- *Yantanglestes conexus* (Yan & Tang, 1976) (1.1)

Pantodonta Cope, 1873
Bemalambdidae Chow, Zhang, Wang & Ding, 1973
- Bemalambdidae gen. et sp. indet. (1.1)
- *Bemalambda* sp. (1.1)

Harpyodidae Wang, 1979
- *Harpyodus euros* Qiu & Li, 1977 (1.3a)

Pantolambdodontidae Granger & Gregory, 1934
- *Archaeolambda tabiensis* Huang, 1977 (2.2)

Pastoralodontidae Chow & Qi, 1978
- *Altilambda pactus* Chow & Wang, 1978 (1.3b?)
- *Altilambda yujingensis* Wang, Yu & Li, 1992 (1.3b?)
- *?Altilambda tenuis* Chow & Wang, 1978 (1.3a)

Arctostylopida Cifelli, Schaff & McKennna, 1989
Arctostylopidae Schlosser, 1923
- *Sinostylops promissus* Tang & Yan, 1976 (2.2)

Tillodontia Marsh, 1875
Plethorodontidae Huang & Zheng, 1987
- *Plethorodon chienshanensis* Huang & Zheng, 1987 (1.1)

Family indet.
- *Simplodon qianshanensis* Huang & Zheng, 2003 (1.3b)
- *Benaius qianshuiensis* Wang & Jin, 2004 (1.1)

Cimolesta McKenna, 1975
Sarcodontidae Lopatin & Kondrashov, 2004
- *Hyracolestes ermineus* Matthew & Granger, 1925 (2.2)

Order indet.
Family indet.
- *Wania chowi* Wang, 1995 (1.3a)
- *Obtususdon hanhuaensis* Xu, 1977 (2.1, 1.3a)
- *Decoredon elongetus* Xu, 1977 (1.3a)
- *Anchilestes impolitus* Chiu & Li, 1977 (1.1)

Note: Figure translations are in progress. See original paper for figures.