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On the geological age of mammalian fossils from Shanmacheng, Gansu Province

ZHANG Zhao-Qun WANG Jian

(*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 zhangzhaoqun@ivpp.ac.cn)

Abstract The mammalian fossils (*Mimolagus* and *Anagalopsis*) from Shanmacheng in the Jiuxi Basin described by Bohlin in 1951 have long been enigmatic in systematics and controversial in the geological age. New survey in this area suggests the fossils were discovered from the Shanmacheng Member of the Huoshaogou Formation. Comparisons of the Shanmacheng fossils with new specimens of *Mimolagus* from the Irdin Mahan Formation, and *Anagale* from the Late Eocene Ulan Gochu Formation, Nei Mongol, suggest an Eocene age for the Shanmacheng fossils. Reinterpretation of the fossil horizon and the paleomagnetic data of Dai et al. (2005) indicates the polarity zones from Huoshaogou section can be correlated to GPTS Chrons 13−18. Therefore, the Huoshaogou Formation may cover late Middle Eocene to Late Eocene and Bohlin's fossil horizon can roughly be correlated to Chron18n (~39−40 Ma) of late Middle Eocene. The late Middle Eocene age of *Mimolagus rodens* narrows the time gap with its close relative *Gomphos* that have been recorded from Early to Middle Eocene. The archaic group Anagalidae may have become extinct before Oligocene.

Key words Shanmacheng, Jiayuguan, Gansu; Eocene; *Mimolagus*, *Anagalopsis*; geological age

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1 Introduction

Bohlin (1951) described three mammalian fossil taxa, e.g. *Mimolagus rodens*, *Anagalopsis kansuensis* and an ungulate, from Shih-her-ma-ch'eng (Shanmacheng), Hui-hui-p'u area, western Kansu (Gansu), China collected during the Sino-Swedish expedition. However, due to the uniqueness of the taxa, the geological age of this locality was undetermined, and a tentative correlation to Early Tertiary was made. Later references of its geological age are controversial, with correlation either to Early Tertiary (Hu, 1962), Early Oligocene (Zhou et al., 1977), earlier than Oligocene (Meng et al., 2009), or to Late Eocene or earlier (Wang, 1997). Stratigraphic position of the fossil horizon is also controversial. It has been associated either to Baiyanghe Formation (Zhai and Cai, 1984) or Huoshaogou Formation (Liang et al., 1992). The Jiuxi Basin

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where the fossils were found is an important area for studying the uplift processes of Qinghai-Tibet Plateau and also for oil exploration (Dai et al., 2005; Zhu et al., 2006). Therefore, the geochronology of this fossil locality is important for both geology and evolution of mammals. To relocate the fossil locality, we made a short survey in the early April, 2015. In this paper, we will provide our relocation of the fossil horizon, and discuss the biochronology based on updated understanding of related taxa, biostratigraphy and magnetostratigraphic data.

2 Geographic and geological relocation of the fossil locality

Bohlin (1951) stated that the fossils were collected at Shih-her-ma-ch'eng, on the right bank of the Po-yang-ho (Baiyanghe), some hundred meters north of the main road. We extracted part of Bohlin's illustration from 1940 (Bohlin, 1940: pl. I-1) and compared it with the Google satellite image (Fig. 1). The gulley Bohlin figured is now locally called Shanmacheng gulley after the name of Shanmacheng castle while the Hui-hui-p'u village is named as Xinminpu. Terrestrial sediments are well exposed along the right bank of the gulley, dipping towards south as Bohlin observed. Cretaceous sediments are well exposed in the lower reaches of the gulley. The overlying Paleogene sediments of Huoshaogou, Baiyanghe, and Shulehe formations are well developed. After about 80 years, the main road Bohlin mentioned is not visible, but may be near the castle relics. Tracing from the castle relics northwards, we found "the brick red sandstone or fine conglomerate laid down in very thick bed" on the right bank of the gulley. Referring to the photo (Bohlin, 1951: pl. VII-7), we relocated the fossil horizon and the possible locality (N39°55′31″, E97°46′44″) (Fig. 1). Stratigraphically, the brick red sandstone bed is in the lower part of Huoshaogou Formation, about 40 m above its lower boundary with Cretaceous sediments.

3 Systematics of *Mimolagus* and *Anagalopsis*

Mimolagus has long been an enigmatic taxon. Bohlin (1951) described in detail the morphology of the partial skull, named it as *Mimolagus rodens*, suggesting both lagomorph and rodent characters, and listed it as a duplicidentate. However, he referred the postcranial bones from the same locality as rodent inc. sed. Bleefeld and McKenna (1985) revised these materials and considered *Mimolagus* as a genus of Lagomorpha. When studying the fossils from Qianshan, Anhui Province, Li (1977) named a new family Mimotonidae, including *Mimotona* and *Mimolagus*, showing their similarity and close relationship. *Mimolagus* was also considered as a monotypic genus in the family Mimolagidae (Szalay, 1985; Erbajeva, 1986). Asher et al. (2005) placed *Mimolagus* at the basal position of Lagomorpha in Glires, which was followed and reinforced by Wible (2007) and Fostowicz-Frelik et al. (2015).

Recently Fostowicz-Frelik et al. (2015) reported a new species, *Mimolagus aurorae*, from the lower beds of Irdin Mahan Formation, Erlian Basin, Nei Mongol. With only a few teeth and some postcranials, the new species show strong similarity with the type species *M. rodens* in many characters. The dI2 is narrow and lacks the anterior groove which is developed

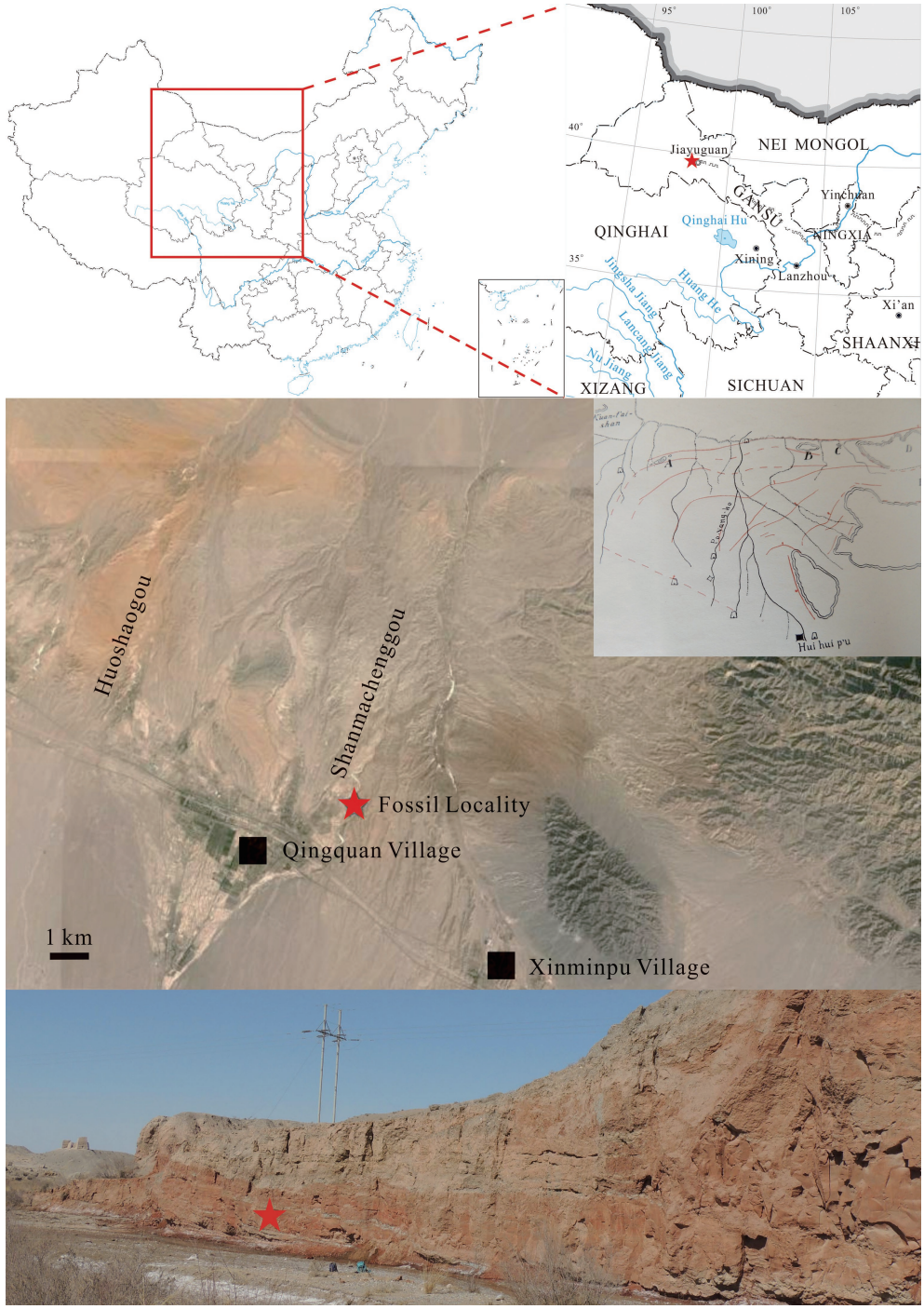

Fig. 1 Geographic map of the fossil locality near Shanmacheng, west of Jiayuguan City, Gansu Province
The Google satellite image shows the location of the fossil locality with the partial figure from Bohlin (1940) for comparison. The field photo at the right bank of Shanmacheng gulley indicates exposure of "the brick red sandstone or fine conglomerate laid down in very thick bed". The red star marks the fossil level of Bohlin (1951)

in Lagomorpha, upper cheek teeth are unilateral hypsodonty. The ankle bones are close in both morphology and size. The calcaneus size of *M. rodens* falls in the variation of *M. aurorae*, though the astragalus is slightly smaller. Therefore, the two species are very close if not conspecific.

Anagalopsis was also an enigmatic taxon for Bohlin. He cautiously listed it under Mammalia insertae sedis. In the description and comparison, Bohlin stated the similarities with *Anagale* of Anagalidae, but refrained from referring it to Anagalidae. With more materials found, Zhou et al. (1977) compared *Anagalopsis* with *Linnania lofoensis* from the Paleocene of Nanxiong Basin and grouped them in Anagalidae, and further stated *Anagalopsis* has more derived characters such as larger size, more molarized P4/p4, and reduced M3 than *Linnania* and *Anagale*. Hu (1993) confirmed the systematic position of *Anagalopsis* using cladistic analysis, which is nested in the clade of Anagalidae.

4 Geological age of *Anagale*

The type specimen (well preserved skull, jaws and postcranials) was discovered from the lower part of Ulan Gochu Formation, at Twin Oboes, Nei Mongol (Inner Mongolia) by Chinese assistant "Buckshot" during Central Asian expedition in 1928 (Simpson, 1931). Together with *Anagale*, some remains of *Embolotherium* of Brontotheriidae were also found. Ulangochuian age was named by Romer (1966) after the fauna from Ulan Gochu Formation, as representing the Early Oligocene Asian Land Mammal Age. The Ulangochuian was correlated with Chadronian age of North America and Sannoisian age of Europe. Hence, Ulangochuian has been widely cited as Early Oligocene till 1997 Wang Banyue introduced the updated dating of the E/O boundary and the realigned age of Chadronian of North American Land Mammal Age, and revised the Ulangochuian as representing Late Eocene.

5 Magnetostratigraphic study in Jiuxi Basin

Huang et al. (1993) did magnetostratigraphical work in Jiudong and Jiuxi basins including a section in Huoshaogou (Fig. 1), where the Huoshaogou Formation was originally named. Referring the mammal fossils and pollen data from Huoshaogou Formation, they correlated the magnetozones 10−12 to Early Oligocene. The most recent work in the Huoshaogou section was carried out by Dai et al. (2005). Totally 11 normal and 11 reversal polarity zones were recognized in the Huoshaogou Formation. They cited the Shanmacheng fossils in the basal Baiyanghe Formation, as indication of no later than Early Oligocene. They further cited typical Oligocene mammalian data from a locality of Baiyanghe Formation a few hundred kilometers away. Hence, they correlated the polarity zones in the Huoshaogou Formation to Chrons 13−18n respectively.

6 Reinterpretation of the geological age of *Mimolagus* and *Anagalopsis*

By comparison with the Eocene *Anagale* and *Mimolagus* from Nei Mongol, *Mimolagus*

rodens and *Anagalopsis kansuensis* from Shanmacheng may also be Eocene in age. Our survey shows the locality should be in the lower part of Huoshaogou Formation, not in the lower part of Baiyanghe Formation. The brick red sandstone and conglomerate level in the Shanmacheng section can be correlated to the Shanmacheng Member of Huoshaogou Formation in the Huoshaogou gulley. With the updated understanding of the biostratigraphy, the polarity zones of Dai et al. (2005) showing dominantly normal polarity, can be correlated to GPTS Chrons 13−18. Therefore, Bohlin's fossil horizon can roughly be correlated to Chron 18n (~39−40 Ma), late Middle Eocene in age (Fig. 2).

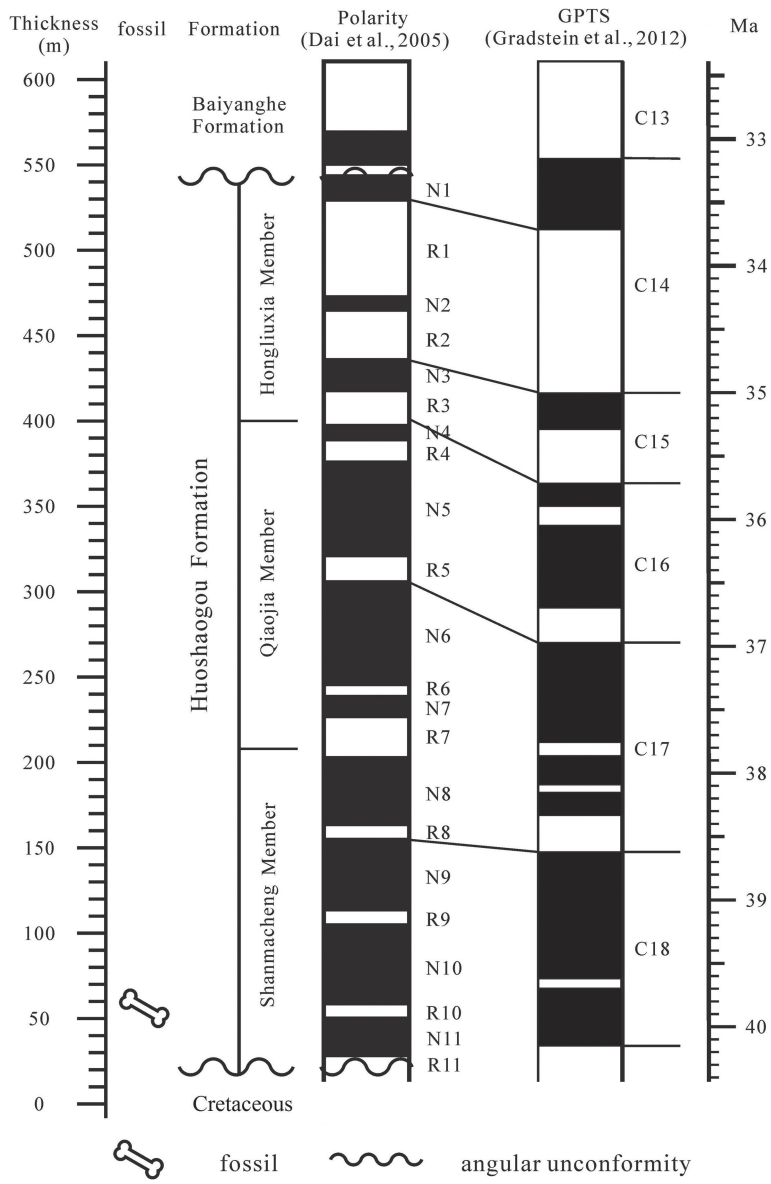

Fig. 2 Reinterpretation of the paleomagnetic data of Dai et al. (2005) with the fossil horizon marked

7 Conclusive remarks

With the updated data and new interpretation of the paleomagnetic data, the Huoshaogou Formation in the Jiuxi Basin may be referred to late Middle Eocene-Late Eocene in age. The late Middle Eocene age of *Mimolagus rodens* narrows the time gap with its close relative *Gomphos* that have been recorded from Early to Middle Eocene (Meng et al., 2004, 2009). The archaic group Anagalidae may have become extinct before Oligocene.

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甘肃骟马城哺乳动物化石地质年代的新认识

张兆群 王 健

(中国科学院脊椎动物演化与人类起源重点实验室，中国科学院古脊椎动物与古人类研究所 北京 100044)

摘要：步林(Bohlin, 1951)描述的酒西盆地骟马城(又译为十二马厂)化石(*Mimolagus*和*Anagalopsis*)在分类位置与地质年代上长期存在争议。步林认为仅依据这些化石无法确定其年代，只是推测可能为第三纪的早期。后人根据*Anagalopsis*与内蒙古发现的*Anagale*对比，认为该化石点大致时代为早渐新世。化石出自哪个层位也有不同的认识。有人认为化石发现在白杨河组下部，也有人认为化石层位属于火烧沟组。鉴于其重要意义，我们于2015年4月赴酒西盆地进行了调查。根据步林的地理位置描述与照片(Bohlin, 1940, 1951), 我们初步确定化石地点应位于骟马城沟内，火烧沟组下部骟马城段。对比内蒙古二连盆地伊尔丁曼哈组新发现的*Mimolagus*以及晚始新世乌兰戈楚组的*Anagale*, 认为步林描述的化石时代也应为始新世。根据对化石产出层位的重新认识，并对比戴霜等(2005)在火烧沟剖面的磁性地层学资料，推测火烧沟组的时代为中始新世晚期至晚始新世，骟马城化石层位的地质年代大致为中始新世晚期。*Mimolagus*的生存年代与其近亲*Gomphos*的差距大大减小，古老的Anagalidae也应该在渐新世之前就已全部灭绝。

关键词：甘肃嘉峪关骟马城，始新世, *Mimolagus*, *Anagalopsis*, 地质年代

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