Terrestrial Mio-Pliocene Boundary in the Linxia Basin, Gansu, China

DENG Tao[1,*], HOU Sukuan[1,2], SHI Qinqin[1,2], CHEN Shaokun[1,2], HE Wen[3] and CHEN Shanqin[3]

1 *Key Laboratory of Evolutionary Systematics of Vertebrates, Institute of Vertebrate Paleontology and Paleoanthropology, the Chinese Academy of Sciences, Beijing 100044, China*
2 *Graduate School of the Chinese Academy of Sciences, Beijing 100039, China*
3 *Hezheng Paleozoological Museum, Hezheng, Gansu 731200, China*

Abstract: The Lower Pliocene of the Linxia Basin in Gansu Province is one of only a few representative sections for the Early Pliocene sedimentary records in northern China, and even in East Asia. Recently, abundant mammalian fossils were found from the base of red clays of the Lower Pliocene Hewangjia Formation at Duikang in Guanghe County within this basin. Previously, the Pliocene mammals were sparsely found in China, and most were collected from fluvial and lacustrine deposits in the eastern Loess Plateau. Mammals from the widely distributed Pliocene *Hipparion* Red Clay are less in number. The known fossils from Duikang include 20 species and belong to the Shilidun Fauna. Their faunal components are similar to the Early Pliocene Gaozhuang Fauna from Yushe, Shanxi. On the other hand, some taxa from Duikang have not been found in the Gaozhuang Fauna, are slightly more primitive in evolutionary level, and appeared mainly in the Late Miocene. As a result, the age of the Duikang fossils may be slightly earlier than that of the Gaozhuang Fauna and closer to the lower boundary of the Pliocene. The Duikang fossiliferous bed is 0.8 m above the top of the Late Miocene Liushu Formation, and the first occurrence of the three-toed horse *Hipparion pater* can be regarded as a biostratigraphical marker of the Miocene/Pliocene boundary. In conclusion, Duikang is an ideal candidate locality to establish as the stratotype of the lower boundary of the Chinese terrestrial Pliocene.

Key words: Miocene, Pliocene, boundary stratotype, mammalian fauna, *Hipparion* Red Clay, Linxia Basin

1 Introduction

The Linxia Basin in Gansu Province is very rich in mammalian fossils from the Late Oligocene *Dzungariotherium* fauna to the Early Pleistocene *Equus* fauna. Among them, the Late Miocene *Hipparion* fauna has the most massive fossil specimens and localities. However, the Pliocene fossil localities were rarely found in the Linxia Basin previously, producing very few taxa and specimens. Recently, a 45 m long fossil lens was discovered from the red clays of the Early Pliocene Hewangjia Formation at Duikang in Zhuangheji Township, Guanghe County (Fig. 1). Cutting into many blocks that were 1 m long, the whole lens was successively excavated and moved into the Hezheng Paleozoological Museum. Some taxa in the large-sized lens were also found at Shilidun and Yinchuan in the Linxia Basin several years ago (Deng et al., 2004a, b; Deng, 2005), and some taxa are very similar to the large mammals of the Gaozhuang Fauna from Yushe, Shanxi (Deng et al., 2010). Duikang is not far from Shilidun, with a linear distance of only 4.75 km. The Duikang fossils belong to the Early Pliocene Shilidun Fauna. In China, the Early Pliocene fossil localities are infrequent, especially localities of large mammals, which, in the past, were found mainly from the fluvial and lacustrine deposits in eastern Loess Plateau, typically represented by the Yushe Basin in Shanxi Province (Qiu, 1987; Qiu et al., 1987; Flynn et al., 1991). The Pliocene fossils from red clays are very scarce. This has been a puzzle to Chinese researchers of the Neogene mammalian fossils, because the traditional methods of stratigraphical correlations depending on large mammals are difficult to use in the Pliocene strata of red clays. We investigated the fossil locality at Duikang, and initially identified the fossils collected from this fossiliferous lens. Our investigation proves that the red clays of the Late Miocene Liushu and Early Pliocene Hewangjia formations are well exposed at Duikang.

* Corresponding author. E-mail: dengtao@ivpp.ac.cn

Besides the huge fossiliferous lens in the Hewangjia Formation, mammalian fossils are produced from the greyish-green mudstones in the top part of the Liushu Formation. The fossils from the Hewangjia lens are very abundant and include some new taxa; their age may be slightly earlier than that of the Gaozhuang Fauna.

In the past, Yushe Zone II and the Jinglean Age were used to represent the Chinese Pliocene mammalian ages. However, the mammals of Yushe Zone II did not come from a certain locality or localities, or from an exact horizon. They were composited by Teilhard de Chardin depending on his judgment for their evolutionary levels, among which there were fossils from not only lower but also upper horizons (Teilhard de Chardin and Young, 1933; Licent and Trassaert, 1935). The Jinglean Age was established based on several mammalian species from the west of Hefeng in Jingle, Shanxi, including the true elephant whose age was impossibly earlier than 3 Ma, and some more primitive taxa (Teilhard de Chardin and Young, 1930). Other Pliocene large mammal assemblages were collected from Youhe in Weinan, Shaanxi, Dongyaozitou in Yuxian, Hebei, and Leijiahe and Renjiagou in Lingtai, Gansu. Among them, only the Gaozhuang Fauna belongs to the Early Pliocene, and only Hefeng and Renjiagou faunas are collected from red clay deposits. The other faunas were found from the Late Pliocene fluvial and lacustrine deposits.

In 1930, Teilhard de Chardin and Young discovered mammalian fossils during their investigation of red clays in the Jingle area. They described the red clay (or loam) deposits as three layers named A, B, and C. The Hefeng Fauna was collected from Red Clay A and included *Hipparion houfenense*, *Antilospira licenti*, *Gazella blacki*, *Cervus* sp., Rhinocerotidae gen. indet., *Elephas* sp., etc. (Teilhard de Chardin and Young, 1930). Chen (1994) found two other mammalian species, i.e. *Nyctereutes sinensis* and *Metailurus* cf. *major* from Hefeng. Yue and Zhang (1998) used magnetostratigraphic analysis, which indicated that the age of Red Clay A is 3.0–2.5 Ma, belonging to the Late Pliocene. Zhang et al. (1999) reported the mammalian fossils excavated from red clays at Renjiagou in Lingtai, Gansu, which included *Chardinomys* sp., *Nyctereutes sinensis*, Gomphotheriidae gen. indet., *Hipparion houfenense*, Rhinocerotidae gen. indet., *Paracamelus* sp., *Gazella* sp., *G. blacki*, and *Antilospira licenti*. The magnetostratigraphic age was 3.4–3.5 Ma, i.e. the early Late Pliocene.

The fossils from Duikang are much richer in taxa and earlier in age than those from red clays at Hefeng and Renjiagou. As a result, the Linxia Basin is a unique area to find mammalian fossils from the Early Pliocene red clays, which provides an ideal candidate stratotype in order to establish the lower boundary of the Chinese terrestrial Pliocene.

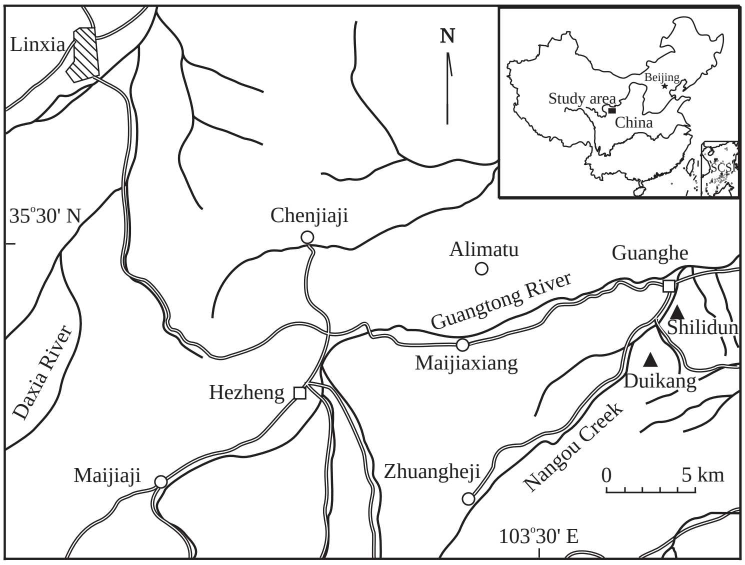

Fig. 1. Location map of the studied area in the Linxia Basin.

2 Geological Setting

The Linxia Basin is located on the triple-junction of the northeastern Tibetan Plateau, West Qinling and the Loess Plateau, delineated by high angle deep thrusts. It is a sub-basin of the Longzhong Basin. The lateral extent of the Linxia Basin is marked by structural boundaries on the northern, western, and southern edges, but is poorly determined towards the east. The basin is filled with 700–2000 m of thick late Cenozoic deposits, which are mainly red in color and dominated by lacustrine siltstones and mudstones punctured by fluvial conglomerates or sandstones, and 30–200 m of the Quaternary loess. The Yellow River and its main tributaries, the Daxia and Tao rivers, intermittently incise the whole late Cenozoic strata and expose complete sections, rendering them convenient for study (Li et al., 1995). To the west and south, the major basin-bounding faults within the Tibetan Plateau are the Leijishan and North Qinling faults, respectively. The Cenozoic deposits of the Linxia Basin begin with the Late Eocene deposits. The sedimentary rocks of the Linxia Basin overlap the Cretaceous sedimentary rocks in the Maxian Mountains to the north. Throughout the central part of the Linxia Basin, the oldest deposits were laid down on the granite of an inferred Paleozoic age. Southwest of the Linxia Basin, the Tibetan Plateau consists of Devonian-Permian terrestrial and marine deposits and Triassic submarine fan deposits (Zhang et al., 2010), which were shed by the east-southeast striking Qinling mountain belt to the east of the plateau (Fang et al., 2003).

Prior to the 1960s, the Cenozoic deposits of the Linxia Basin were simply called the Gansu Series. In 1965, the First Regional Geologic Survey Team of the Gansu Geological Bureau created a new name, Linxia Fm., for the whole Cenozoic sequence, subdivided it into four members (1 to 4), and dated the whole sequence as Pliocene based on some *Hipparion* fossils found in the upper-most part of the sequence. Qiu et al. (1990) created a new formation, Jiaozigou Formation, for the lower part of the section, corresponding to the members 1 and 2 of the Linxia Formation, and thus, restricted the Linxia Formation to the members 3 and 4. A research group from Lanzhou University resubdivided the late Cenozoic deposits of the Linxia Basin in 1990s, nominating a series of new lithological units and dating them mainly by the paleomagnetic method (Li et al., 1995; Fang et al., 1997, 2003). Deng et al. (2004a, b) and Qiu et al. (2004b) revised the lithological sequence, and adopted the following units: the Oligocene Tala and Jiaozigou, the Miocene Shangzhuang, Dongxiang, Hujialiang, and Liushu, the Pliocene Hewangjia and Jishi, and the Early Pleistocene Wucheng formations.

Fig. 2. Photo of the Duikang section in the Linxia Basin, showing the position of the fossiliferous lens in the Hewangjia Formation.

Both the Late Miocene Liushu and Early Pliocene Hewangjia formations are red clay deposits, bearing abundant fossils of the *Hipparion* fauna. Sedimentological and geochemical studies proved that this Neogene red clay is windblown in origin as is the overlying Pleistocene loess (Ding et al., 1998; Guo et al., 2001). One of the most striking features of the red clay sequence is the existence of many horizontal carbonate nodule horizons. The thickness of these horizons ranges from 10 cm to >100 cm, with most of the nodules being <10 cm in diameter. The cement matrix within most of the nodule horizons is a reddish, weathered soil material.

The Liushu Formation consists of light yellowish-brown carbonate-cemented siltstones intercalated with a few thin beds of mudstones and marlites, developing substantial mottles and big carbonate nodules. The Hewangjia Formation consists of yellowish-brown calcareous mudstones encompassing big carbonate nodules intercalated by many marlite beds, with basal conglomerates that are thicker in the western part of the Linxia Basin and thinner in the eastern.

The strata at Shilidun in Guanghe County are well exposed and include the Hujialiang, Liushu, Hewangjia, and Jishi formations. The fossiliferous bed at Shilidun is situated within the red clays, 3 m above the basal conglomerate of the Hewangjia Formation, and contains *Hystrix gansuensis*, *Alilepus* sp., *Promephitis* sp., *Chasmaporthetes* sp., *Hyaenictitherium wongii*, *Cervavitus novorossiae*, *Palaeotragus* sp., *Samotherium* sp., *Protoryx* sp., *Sinotragus* sp., and *Capricornis* sp. (Deng, 2004a, 2009).

3 Duikang Section

Duikang is located 6.5 km southwest of the Guanghe County seat, near Nangou Creek, a branch of the Guangtong River (Fig. 1). The fossiliferous locality is situated on the southwest escarpment of the upper Shuimo Gully on the southeast slope of Nangou Creek, with an elevation of 2153 m (Fig. 2). The Shuimo Gully's outlet to Nangou Creek is located at the village Xinzhuang, with an elevation of 2060 m. Our measured section begins from the lower end of the Shuimo Gully (35°25'39.8"N, 103°32'48.3"E) and terminates on the upper end of this gully (35°25'22.1"N, 103°32'59.6"E), with a total thickness of >84 m. This section includes two informations: the lower part is the Late Miocene Liushu Formation whose top greyish-green mudstones contain *Hipparion* sp. and

Sinotragus sp., and the upper part is the Early Pliocene Hewangjia Formation, whose basal red clays contain a huge fossiliferous lens (Fig. 3). The section is capped by the Late Pleistocene Malan Loess. It is described from top to bottom as follows:

Late Pleistocene Malan Loess

13. Greyish-white silty clays, bearing a lot of plant roots and snail fossils

-----------------Disconformity---------------

Early Pliocene Hewangjia Formation

12. Interbedded brownish-yellow silty mudstones and muddy siltstones with calcareous cement. A single mudstone bed is 1.5 m thick, with many greyish-green marlite bands, and a single siltstone bed is 60 cm thick. Not to top. >15 m

11. Brownish-red silty mudstones intercalating many brownish-yellow calcareous nodule beds. A single mudstone bed is about 40 cm thick, and a single nodule bed is 10–20 cm thick. The fossiliferous lens described in this paper was excavated from the bottom of this layer. 10.8 m

Late Miocene Liushu Formation

10. Blocky brownish-yellow calcareous siltstones with hard cementation, containing rich fine crystalline calcites. Iron-manganese components have a dotted distribution and form coatings on fissure surfaces. 1.66 m

9. Thick-bedded greyish-green sandstone and conglomerate lenses, changing into interbedded brownish-red silty mudstones and muddy siltstones. The lenses have partial brownish-yellow impregnation, with moderate psephicity and sorting, and hard cementation. The surfaces of gravels are frequently oxidized to red. The top of this layer consists of greyish-green mudstones with a thickness of 56 cm, bearing sandy components, and partly containing coarse sands or fine gravels. *Hipparion* sp. and *Sinotragus* sp. were discovered from the top part of this layer. 8.62 m

8. Thick-bedded light brownish-red silty mudstones banding yellowish-brown muddy siltstones, with small greyish-green sandstone and conglomerate lenses. 12.75 m

7. Thin-bedded greyish-green sandstones and conglomerates in lower part, with high psephicity, loose cementation, and poor sorting; two thick calcareous siltstone beds banding a muddy siltstone bed in the middle part, with hard cementation and richly dotted with crystalline calcites; greyish-green sandstones and conglomerates in the upper part, changing to large lenses with high psephicity and loose cementation. ~8 m

6. Thick-bedded brownish-red muddy siltstones banding two thick calcareous siltstone beds, with a small amount of fine gravels, hard cementation, crystalline vein, and miarolitic calcites. 6.8 m

5. Interbedded light yellowish-brown and brownish-red muddy siltstones, and interbedded brownish-red muddy siltstones and calcareous siltstones. Each bed is about 50 cm thick. Muddy siltstone beds contain white amorphous calcites and reticular iron-manganese coatings. Calcareous siltstones have hard cementation, containing many fine grains with diameters of 2–4 mm. 6.93 m.

4. Light greyish-green muddy siltstones with dotted iron-manganese components, containing calcareous nodules with diameters from 3 cm to >10 cm. 0.71 m.

3. Interbedded brownish-red muddy and calcareous siltstones with iron-manganese coatings. The calcareous siltstones have hard cementation, containing worm tubes and plant roots that are filled by muddy components. 8.95 m.

2. Greyish-green siltstones and fine sandstones with dotted iron-manganese components, containing quartzose coarse sands or fine gravels as well as white amorphous calcites. 1.24 m.

1. Light brownish-red silty mudstones dotted with iron-manganese components banding a 20 cm thick greyish-green siltstone bed with hard cementation. Not to bottom. >2.72 m

4 Mammalian Fossils

The following is a preliminary list of the mammalian fossils from Duikang, including Rodentia: *Hystrix gansuensis*; Lagomorpha: *Alilepus* sp.; Carnivora: *Sinictis dolichognathus*, *Parataxidea sinensis*, *Hyaenictitherium wongii*, *Adcrocuta eximia*, *Chasmaporthetes kani*, and *Felis* sp.; Perissodactyla: *Hipparion hippidiodus*, *H. platyodus*, *H. licenti*, *H.* (*Proboscidipparion*) *pater*, *Shansirhinus ringstroemi*, *Hesperotherium* sp., and *Ancylotherium* sp.; Artiodactyla: *Cervavitus novorossiae*, *Palaeotragus microdon*, *Samotherium* sp., *Sinotragus* sp., and *Gazella blacki*.

The above-mentioned 20 mammal species can be divided into two groups: (1) forms same as or close to those of the Gaozhuang Fauna, such as *Chasmaporthetes kani*, *Hipparion licenti*, *H. platyodus*, *H. pater*, *Shansirhinus ringstroemi*, *Cervavitus novorossiae*, *Hystrix gansuensis*, *Hyaenictitherium wongii*, and *Gazella blacki*; (2) forms not found in the Gaozhuang Fauna, such as *Sinictis dolichognathus*, *Parataxidea sinensis*, *Adcrocuta eximia*, *Felis* sp., *Hipparion hippidiodus*, *Ancylotherium* sp., *Palaeotragus microdon*, *Samotherium* sp., and *Sinotragus* sp., which were at a slightly lower evolutionary level and appeared mainly in the Late Miocene. Important characters of the fossil species from Duikang are briefly described as follows.

Hystrix gansuensis is a large-sized porcupine (Fig. 4a). The nasals are enlarged, and their anterior ends are more retracted than those of the premaxillae. The nasals and premaxillae form an obvious nasal notch. The frontal surface is broad, with a prominent central part of the posterior margin. The skull roof is strongly constricted in the parietal area. The parietal bones are small and their posterior margins have a wide V-shaped depression that contains the triangular interparietal bone. The parietal crests are weak and rapidly convergent. In lateral view, the swollen frontal bones form a steep slope from the parietal bones. The diastema between I2 and P4 is long. The muzzle is high. The infraorbital foramen is large, with a posterior margin above the middle of M1. The orbit is large and its anterior rim is above the posterior margin of M2, lacking a postorbital process. The zygomatic process of the zygomatic bone is strongly posteriorly extended, and even exceeding the posterior end of the zygomatic arch. The zygomatic process of the temporal bone is short, not reaching the middle of the orbit. The horizontal ramus of the mandible is narrow and long. The diastema between i2 and p4 is shorter than the length of the cheek tooth row. The mental foramen is located under the anterior margin of p4. The masseteric fossa is shallow, with a weak upper masseteric ridge, but has a well-developed lower masseteric ridge, curvedly extending superio-anteriorly and reaching the anterior margin of p4. The cheek teeth are medium-hypsodont.

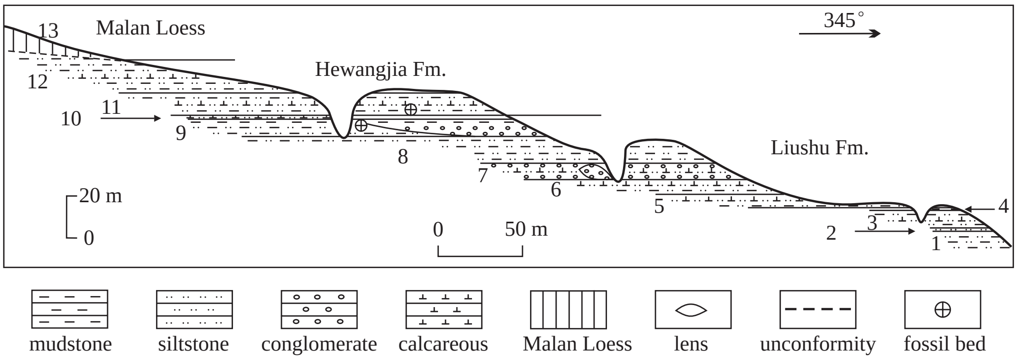

Fig. 3. Schematic section at Duikang in Guanghe County, Gansu Province.

Sinictis dolichognathus is a large-sized mustelid. The Duikang specimen is larger than the Baode specimens (Zdansky, 1924). In dorsal view, the postorbital region is obviously constricted, and the temporal lines are rapidly convergent, uniting into a high sagittal crest. In lateral view, the muzzle and nostrils are low. There is a marked depression in front of the orbit, which makes the orbital border clear. The anterior rim of the orbit is above the anterior root of P4. The infraorbital foramen is narrow and moderate in size, and is located under the front of the orbit and above the anterior part of P4. The zygomatic arches are fine. The lower margin of the horizontal ramus of the mandible is roundly curved at front and straight at back. There are two mental foramens under p2 and p3, respectively. I1 and I2 are very small, but I3 is markedly enlarged. C is very large and long, and its tip does not exceed the lower margin of the horizontal ramus in occlusion. There are diastemata between the premolars. P1 is small and close to C. P2 is double-rooted, and its main cusp has a straight anterior margin and a concave posterior margin. P3 is similar to P2 in shape, but much larger than P2 in size. P4 is long, and its parastyle is cingulum-like; the paracone is high, with an oblique anterior margin that is much longer than the posterior margin, with a rounded carnassial notch from the metastyle. In lateral view, both the paracone and metacone are low, but the former is obviously larger and higher than the latter, between which a groove exists; the labial cingulum is absent. Both p3 and p4 have a single cusp and double roots.

Parataxidea sinensis is a small badger with a short muzzle (Fig. 4b). The nasals are wide at the front and back, but constricted at the middle. In dorsal view, the sagittal groove is wide and shallow. The temporal lines are rapidly convergent, forming a weak sagittal crest. In lateral view, the dorsal border is posterio-superiorly oblique and slightly concave. The zygomatic arches are strongly curved. Both postorbital processes of the zygomatic and frontal bones are well-developed. The infraorbital foramen is located above the P3/P4 boundary and under the anterior rim of the orbit. The lower margin of the orbit is located at the middle of the height of the skull. The labial surface of the mandibular symphysis is convex and rough, with a marked sagittal groove. The horizontal ramus is narrow, and its lower margin is almost straight behind p3. The mental foramen is large, and is located under the anterior margin of p2 and near the lower margin of the horizontal ramus. The incisors are strong. I/i1 are similar to I/i2 in size, while I/i3 are markedly enlarged. C is straightly inferiorly extended, and c is exterio-superiorly extended. The labial cingulum is absent on the cheek teeth. P/p2 and P/p3 are robust, with a high main cusp for each of them. P4 is the longest among the upper cheek teeth; the paracone is conical and slightly higher than the metacone, with a long anterior margin and a concave base; the parastyle is very low and tiny; there is a groove between the metacone and paracone. M1 is transversely wide and low, and convex at the labial side.

Hyaenictitherium wongii: this hyaena from Duikang is larger than that from Baode in size. In dorsal view, the nasals are narrow and long, exceeding the anterior rim of the orbit. The sagittal depression of the frontal bones

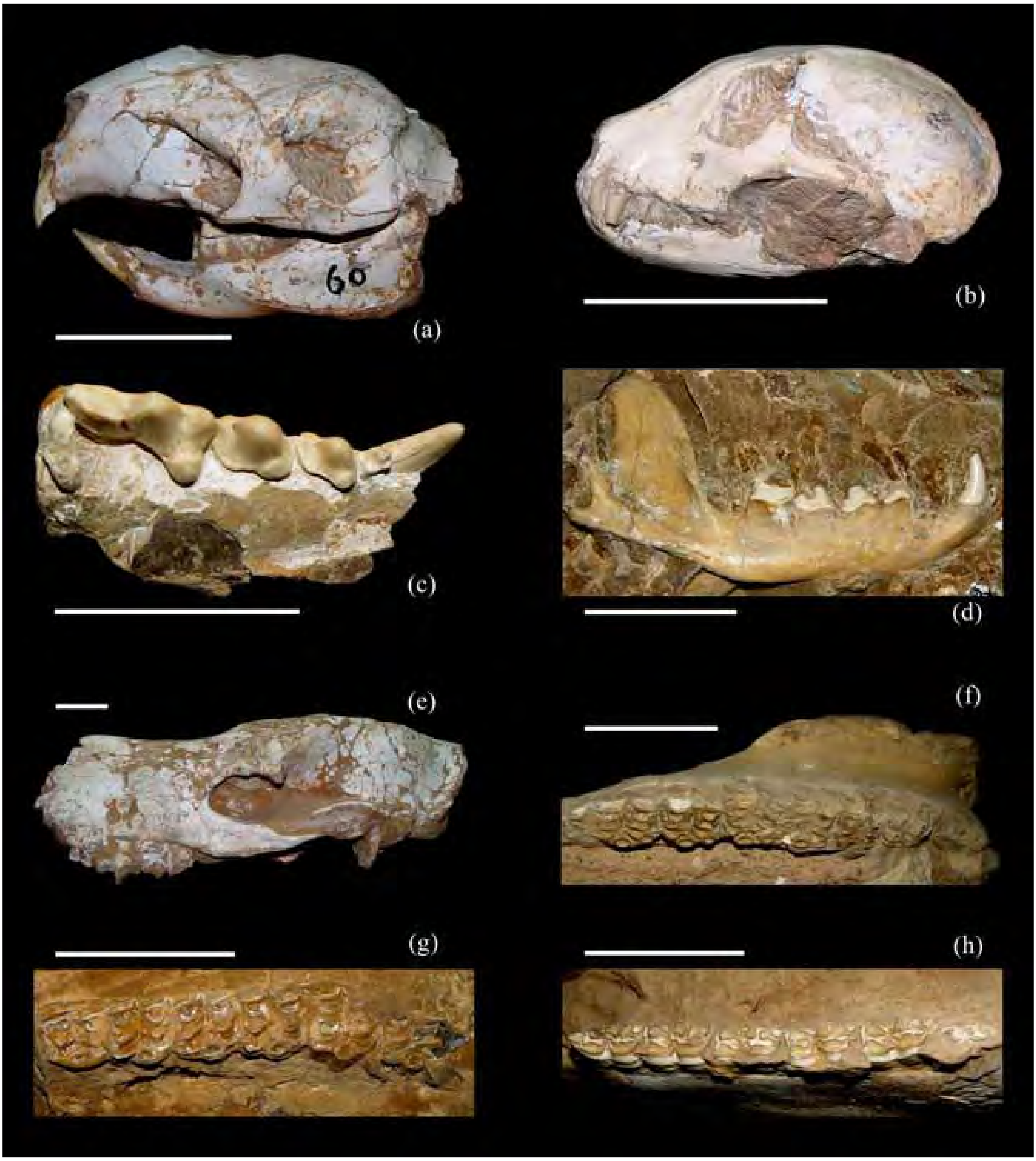

Fig. 4. Mammalian fossils from the basal part of the Hewangjia Formation at Duikang in the Linxia Basin. Scale bars = 5 cm.
(a) Skull and mandible of *Hystrix gansuensis*, lateral view; (b) Skull and mandible of *Parataxidea sinensis*, lateral view; (c) Right upper jaw with dentition of *Chasmaporthetes kani*, occlusal view; (d) Right mandible of *Hyaenictitherium wongii*, lateral view; (e) Skull of *Ancylotherium* sp., lateral view; (f) Left upper jaw with cheek teeth of *Hipparion pater*, occlusal view; (g) Right upper cheek teeth of *Hipparion platyodus*, occlusal view; (h) Left lower cheek teeth of *Hipparion pater*, occlusal view.

between the parietal crests is marked. The braincase is narrow and the zygomatic arches are strongly expanded laterally. In lateral view, the orbit is round, with a sharp lower rim, and its anterior rim is located above the middle of P4. The infraorbital foramen is rounded and located above P3. There is a long distance between the postorbital processes of the frontal and zygomatic bones, so that the orbit has a large posterior opening. The mental foramen is large in size and oval in shape, and is located under the p1/p2 boundary. The anterio-inferior corner of the masseteric fossa is rounded and far from m1 (Fig. 4d). C is thin and long, with an oval cross section and a marked labial cingulum. P2 has a high and relatively flat main cusp, and a well-developed metastyle. P3 is similar to P2 in shape, but is much larger than P2 in size. P4 is prolonged, with a length of 25.4 mm; on the labial side, there is a depression between the parastyle and paracone, and the main cusp is very flat. The parastyle is as long as 2/3 of the paracone, and the metastyle is approximately as long as the metacone. The c is slender and posteriorly curved; there is a wide and rounded ridge on the middle of the labial surface, before and behind which there is a fine groove, respectively. The diastema of c-p1 is long, with a length of 6.3 mm. The main cusps of the lower premolars are high, with a straight anterior margin and a concave posterior margin. The p1 is rudimental and tiny. The p4 has well-developed para- and meta-stylids; the parastylid is conical, and the metastylid is crestiform; the lingual cingulum is marked. The paraconid of m1 has the same length as the protoconid; the anterior part of the lingual cingulum is obvious; the meta- and ento-conids are strong cones and the talonid is well-developed.

Adcrocuta eximia is a large-sized hyaena. The length from the anterior margin of I1 to the posterior margin of M1 is 129.8 mm, the length of I1-P4 is 134.2 mm, and the length of P1–P4 is 88.2 mm. The palatal surface is broad and slightly concave, and the palatal fissure is particularly wide and anteriorly convergent. The posterior palatine foramen is large and rounded, and is located at the level in front of P2. The upper dental formula is 3.1.4.1. The outline of I1 is narrow and oval. I2 is slightly larger than I1, and its posterior margin has a pair of marked supplementary cusps. I3 is very large and caniniform, twice as large as I1 in size, with a distinct posterior cingulum and a well-developed accessory cusp on its exterio-posterior side. In lateral view, the crown of C is straight and extends anterio-inferiorly. P1–P4 are arranged in a straight line and interspaced by short diastemata. P1 is small and conical, shifted near the lingual side of C; the lingual and labial surfaces are convex, the anterior and posterior ridges are well-developed, and the lingual cingulum is remarkable. P2 has a convex labial surface, a concave lingual surface, a rounded anterior margin, a small and low metastyle that is separated by a shallow groove from the main cusp, and a weak cingulum. P3 is notably more robust than P2 in size, but similar to P2 in shape; the anterior edge is distinct and lingually oblique, and the parastyle is weak. The wearing facets of P2 and P3 are horizontal. P4 is 36.8 mm long; the protocone is a small curved ridge; the parastyle is shorter than the paracone that is shorter than the metastyle; the parastyle is sturdy, with a horizontal wearing facet; the wearing facets of the paracone and metastyle are lingually oblique, and the latter is narrow and long. M1 is small and transversely long; the para- and meta-cones are indistinct, and the protocone is large.

Chasmaporthetes kani: this hyaena has anterio-posteriorly flat canines with slightly posteriorly-bended crowns (Fig. 4c). The cheek teeth are high-crowned. The premolars are more slicing, with well-developed accessory cusps that are distinctly apart from the main cusps. P1 is large, high and flat, with a flat lingual surface. P2 is the most obliquely positioned in the cheek tooth row, with a 30° angle between its midline and the row; the main cusps are labially convex and lingually flat; the parastyle is strong and obviously extending lingually. P3 is very similar to P2 in shape, but has a much larger size, a more oblique position, and a more posteriorly-shifted pre-endostyle. The labial ridge of P4 is deeply concave between the parastyle and paracone, with a distinct groove at the corresponding position of the labial wall; three main cusps on the labial ridge are relatively flat; the parastyle is as long as half of the paracone, and the metastyle is approximately as long as the paracone, with a concave labial wall; the protocone is high, lingually rounded and labially flat, with a deep depression apart from the labial ridge. M1 is very large, transversely wide, and located on the posterior-lingual side of P4; the protocone is well-developed and similar to that of P4 in shape. The c is slightly posteriorly curved. The main cusps of the lower premolars are high and robust, and there is a lack of labial cingulum. The p1 is tiny and single-rooted, and is tightly close to c. The p2 has diastemata separating it from p1 and p3. The p2 and p3 lack parastylids, and their metastylids are much lower than the main cusps. The p4 has a well-developed and highly positioned parastylid and a large metastyle. The Duikang specimen of *C. kani* has P1/p1, but the Yushe specimens have none (Qiu, 1987), which indicates that the former is more primitive.

Felis sp. from Duikang is a small-sized felid with a total cranial length of about 110 mm. The skull is short and high. The parietal lines are faint and slowly convergent, forming a short sagittal crest. The frontal surface is broad and convex. The postorbital constriction is unobvious and the braincase is enlarged. The zygomatic arches are strongly laterally expanded, with a maximum width between the postglenoid processes. In lateral view, the depression in front of the orbit is shallow, containing the muffle and upper lip levator in life. The infraorbital foramen is located under the front of the orbit, at the level of the middle of P3. The anterior rim of the orbit is located above the posterior root of P4. The postorbital process is moderately long. I3 is remarkably enlarged and caniniform. C is located on the exterio-superior side of the incisors, and is robust, conical, and slightly posteriorly curved. P2 is absent. The two premolars are simply structured. The main cusp of P3 is high and sharp, with a straight and oblique anterior margin