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RESEARCH ARTICLE

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First report on rhinoceros from the late Neogene Qin Basin of Shanxi, China

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Abstract

Dihoplus is a rhinoceros distributed across East Asia and Europe from the Late Miocene to Pliocene. This study describes a new skull from the Qin Basin in Shanxi Province, China, referred to as *Dihoplus ringstroemi*, which has long been debated in taxonomic identity. This skull confirms that *D. ringstroemi* is an independent species and reveals the presence of the upper incisor and variations in the degree of constriction of the two lingual cusps of upper cheek teeth. In addition, the new skull indicates that the Qin Basin has a late Neogene sediment and fauna comparable to that of the Yushe Basin.

KEYWORDS

Dicerorhini, *Dihoplus*, late Miocene, Pliocene, Qin Basin, Yushe Basin

1 | INTRODUCTION

Dihoplus ringstroemi fossils from Shangyingou of Xinan Basin, Shanxi, and Jijiagou of the Baode Basin, Shanxi, China, described by Ringström (1924) include skull, mandible, postcranial bones, and several juvenile cheek tooth rows. After this, Jijiagou in Baode, Shanxi, became a classic locality of the Late Miocene *Hipparion* fauna in China. Zdansky (1923) first described strata and fossils, and Pei et al. (1963) established the Baodean Stage. The

Baode Formation, with both upper and lower fossiliferous layers, was named by the Shanxi Regional Survey Team in 1978. Most fossils were produced in the lower part of this formation, mainly composed of *Chilotherium*, *Hipparion*, *Samotherium*, and *Gazella*. Faunal comparison and paleomagnetic data suggested an age of 7–6.5 Ma, corresponding to Turolian (MN12) of Europe Land Mammalian Neogene Zone (Deng et al., 2004).

In addition to Xinan and Baode basins, two other localities also produced *D. ringstroemi* in China. In the Linxia Basin, *Dihoplus* is found in localities with ages similar to that of the Baode basin, but with more ample materials (Deng, 2006b; Deng et al., 2013). The Yushe Basin is a famous Pliocene locality in China with a long research history (Deng, 2006a; Deng et al., 2010; Qiu & Qiu, 1995; Teilhard de Chardin & Young, 1933). *Dihoplus ringstroemi*, belonging to the Gaozhuang fauna, is produced in the lower layers and is accompanied by another rhinoceros, *Shansirhinus* (Deng et al., 2010). Faunal comparisons have suggested an Early Pliocene age for Gaozhuang fauna, corresponding to the Ruscinian (MN14) of the Europe Land Mammalian Neogene Zone (Deng et al., 2010; Qiu & Qiu, 1995).

Mammal fossils from the Qin Basin were first mentioned by Teilhard de Chardin and Young (1933), who identified a series of freshwater deposits extending in the Yushe-Wuxiang-Qin basins. During 1934–1935, French missionary Emile Licent conducted excavations and collections in the Yushe and Wuxiang basins; he once prospected large areas of the Qin Basin. Large-scale and detailed investigations of these basins have been conducted since the 1970s. The Geological Bureau of Shanxi Province (1985) surveyed this area and delineated the Cenozoic Yushe Group distribution. However, attention has been paid to the Yushe and Wuxiang basins, and few studies have mentioned fossils or strata in the Qin Basin (Cao, 1980; Qiu et al., 1987; Cao & Cui, 1989; Tedford et al., 2013).

In this study, ~50 km southwest of the Yushe Basin, a new locality was identified in the Jing village of the Qin Basin (Figure 1). The new skull was excavated from the thin yellow-green mudstone of a hill ridge south of Jing village, which is rich in the remains of aquatic mollusks; however, it was not clearly stratified. The underlying mudstone is well-stratified yellow muddy sandstone with granules, and its thickness is unknown, as the lower part is not exposed. The overlying red-brown muddy sandstone with granules also has a stratified structure. In this small section, with a height of less than 7 m, the yellow and red-brown muddy sandstones are interstratified. The mudstone that produced the new skull is relatively thin, ~0.6 m, and its color is yellow and green, indicating a relatively short time and shallow and small water bodies, such as a pond. In the uppermost part of this section, ~4–5 m, we found thick muddy red-brown sandstone with gravel. This gravel shows a weak vertical succession of grain size with two cycles: two units with large cobbles are thin, whereas units with small granules are thick, and the matrix is silt and clay. These sediment characteristics indicate the depositional facies of the braided river or alluvium, but not fine fluvial facies.

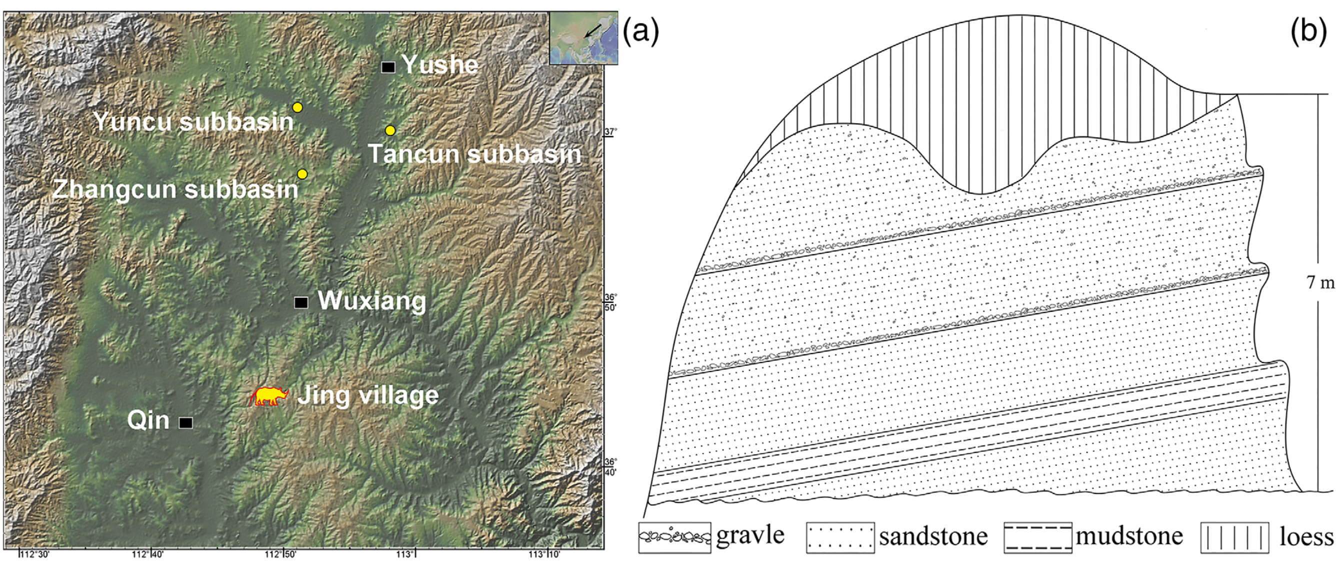

FIGURE 1 Map and section of Jing village in Qin Basin, China. (a) Map of Jing village and nearby basins; (b) section of a new locality at Jing village produced new fossil.

The Qin, Yushe, and Wuxiang basins have been considered together as a large Yushe Basin, with the strata in Yushe County being the most exposed fossiliferous. There are slight differences in strata and lithology among the three basins, including the subbasins (Tedford et al., 2013). The new skull described here was produced from mudstone of the new locality in the Qin Basin. This study examines this new skull to investigate the morphology and taxonomic identity of *D. ringstroemi* and the strata of the Jing locality.

2 | MATERIALS AND METHODS

The fossil described in this study is a skull from the Qin Basin, China. It is partly damaged. The skull roof is crushed downward to form a flat roof. Consequently, the orbit position relative to the frontal roof is inaccurate. This is also true for the outline of the nasal notch in lateral view. The posterior part of the skull is missing. The cheek teeth are moderately worn and the crown is also damaged in the right molars and left P4-M3.

The anatomical terms for the skull and teeth follow Sisson (1953) and Qiu and Wang (2007). The measurements follow the protocol established by Guérin (1980). Term abbreviations: M, upper molar; P, upper premolar. Institution abbreviations: M, Museum of Evolution of Uppsala University, Sweden; MCZU, Museum of Changzhi University, Changzhi University, Changzhi, Shanxi, China.

3 | SYSTEMATIC PALEONTOLOGY

Order Perissodactyla OWEN, 1848
Family Rhinocerotidae GRAY, 1821
Subfamily Rhinocerotinae GRAY, 1821
Genus *Dihoplus* BRANDT, 1878

Type species: *Dihopl schleiermacheri* (Kaup, 1832), Late Miocene (MN9), Eppelsheim, Germany, and near Slatino, Bulgaria (Geraads & Spassov, 2009; Kaup, 1832).

Other species include *Dihoplus pikermiensis* (Toula, 1906), and *Dihoplus ringstroemi* (Arambourg, 1959).

Amended diagnosis: Modified from Pandolfi et al. (2015). Large-sized two-horned rhinoceros. The nasal septum is not ossified. Tooth row rather caudal, nasal notch at premolar level. The occipital area elevated significantly. Cranial basis short, the postglenoid process close to the paroccipital process. Upper premolar primitive, submolariform, with reduced tendency of metacone rib. Upper molars with constriction of lingual cusps. Lower i2 present.

Dihoplus ringstroemi (Arambourg, 1959).
Revision history
1924 *Dicerorhinus orientalis*: Ringström p. 5, figures 1–10, 14–1
1959 *Dicerorhinus ringstroemi*: Arambourg p. 73
2003 *Dicerorhinus ringstroemi*: Giaourtsakis p. 235
2006 *Dihoplus ringstroemi*: Deng p. 51, figure 3
2012 *Dicerorhinus ringstroemi*: Tong p. 556, figures 1e, 2e, and 3e
2015 *Dihoplus megarhinus*: Pandolfi et al. p. 325

Lectotype: M 448 (Museum of Evolution of Uppsala University, Sweden), skull described by Ringström (text-fig. 1–2, 1924).

Type locality and horizon: Xinan County in Henan Province China. Late Miocene.

Amended diagnosis: Modified from Ringström (1924). Large-sized two-horned rhinoceros. Nasal notch and infraorbital foramen at the P4 level. The crista is present on the upper cheek teeth. Upper premolars with weak metacone rib and lingual cingulum. Upper molars with short antecrochet and reduced tendency of lingual cusp constriction. Upper deciduous cheek teeth with weak metacone rib and crista. The incisor was reduced with a small one. *Dihoplus ringstroemi* differs from *Dihoplus schleiermacheri* in having a lingual cingulum in the upper premolars, a retracted nasal notch, and a reduced upper incisor. It differs from *Dihoplus pikermiensis* in having a weaker metacone rib of the upper premolars and a well-developed protoloph of P2.

New referred materials: MCZU 1549, skull, occipital portion missing, containing upper cheek teeth P2–M3 with partly crushed crowns (Figures 2, 3, and Table 1).

3.1 | Description

Skull: In the dorsal view, the maximum width of the skull roof is in the postorbital area, indicating a developed anterior rim of the orbit. In the lateral view, the nasal bone extends downward at the terminal point, below the level of the ventral edge. It is wide, thick, and long, and the nasal horn boss occupies approximately two-thirds of the length of the nasal bone. The frontal area between the orbits is slightly swollen and higher than that of the nasal portion. The rough surface of the

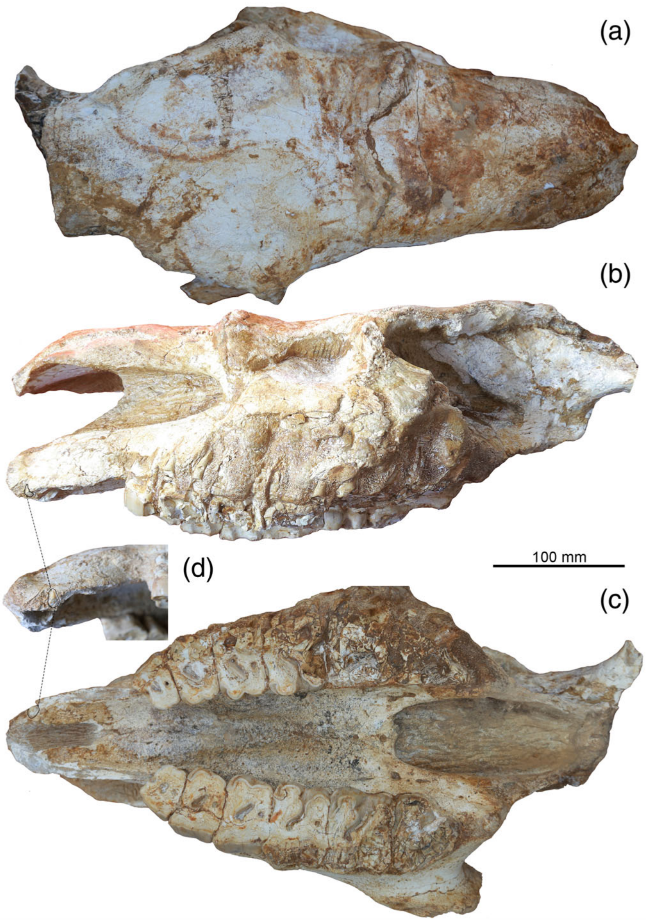

FIGURE 2 Skull (MCZU 1549) of *Dihoplus ringstroemi* from the Qin Basin, Shanxi, China. (a) ventral view; (b) dorsal view; (c) left view; (d) lateral–ventral view of upper incisor.

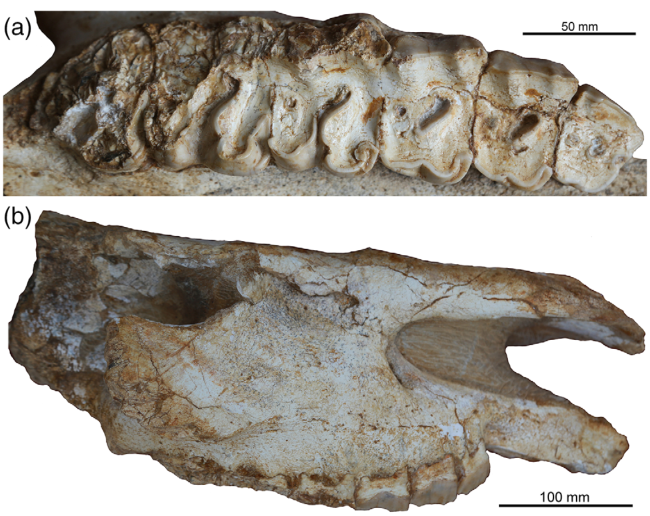

FIGURE 3 *Teeth (MCZU 1549) of Dihoplus ringstroemi* from the Qin Basin, Shanxi, China. (a) upper cheek teeth; (b) right view of skull.

front horn boss extends to the suture with the nasal bone, and a small tubercle is present in the anterior portion. The posterior end of the nasal notch is at the level of P4, and the infraorbital foramen is below the nasal notch at the level of P4. The anterior rim of the orbit is at level of M2. The zygomatic arch is strong below the orbit. The anterior edge of the orbit forms a narrow bone plate protruding laterally (Figure 2b). The premaxilla is slightly larger and stronger and has remained (with a diameter of ~10 mm) of the root of an incisor. The premaxillae on each side are connected and fused with each other at the anterior end, where the bone is robust and has a rugosity surface. The anterior end of the premaxilla is slightly posterior to the nasal tip. The palatine fissure is wide at the anterior portion of the diastema; however, its posterior end remains unknown. The lingual edge of the cheek tooth row is slightly arched and converged anteriorly. The anterior end of the choana is U-shaped and at the level of the middle portion of M2.

Dentition: An anterior tooth represented by a round root is present near the anterior tip of the premaxilla. No other teeth or alveoli are preserved either anterior or posterior to this root. Given the evolution of the incisor and canine in Rhinocerotidae, the tooth appearing in the late Neogene specimens should be the first incisor but not at the anterior end of the premaxilla. Because the root of this tooth is present with width 6 mm wide and 7 mm long, it is recognized as a deciduous incisor. The crown is worn off.

P2–P4 and M1 are moderately worn; however, M2 is less worn. P2 is trapezoidal in outline with a narrower medial edge, and its anterior edge is similar in width to its posterior edge. It has a triangular medifossette formed through the fusion of the protocone and hypocone, and the latter two cusps are similar in size. A narrow and long crista is present at P2 on each side. Because P2 is heavily worn, it is uncertain whether the crochet is present. The labial cingulum is absent; however, the anterior and posterior cingula form the anterior and posterior fossettes. The lingual cingulum is present, but nearly worn off, leaving remains around the protocone. The parastyle is short and the paracone rib is slightly prominent.

P3 is rectangular, with a slightly larger external edge than the medial edge. The parastyle and paracone rib are developed, and the metacone rib is present but weak. The medifossette is narrow and long, parallel to both protoloph and metaloph. The labial cingulum is absent. The lingual cingulum is slender, but continuous. The anterior fossette has worn off and the posterior fossette is round and nearly worn off. P4 resembles P3 in nearly all aspects. Its metacone rib is present but weaker than that of P3. The lingual cingulum is interrupted at the protocone of P4.

TABLE 1 Measures of skull and teeth of *Dihoplus ringstroemi* from the Qin Basin (mm).

Skull	L or W	Teeth	L/W/H
Plate width between P2	63	P2 left	39/46/23
Plate width between M1	78	P2 right	
Plate width between M3	92	P3	43/60/25
Nasal length	232	P4	47/65/20
Distance of orbit-nasal notch	127	M1	55/68/–
		M2	56/73/–
		M3	58/66/–

In M1, the parastyle and paracone rib are developed. The anterior cingulum is also present. The lingual and labial cingula are completely absent. The crochet is short. The antecrochet is wide. There are constrictions in the protocone and hypocone. M2 is similar to M1; however, the protocone constriction is slightly weaker. M3 has a triangular outline. Because they are largely broken, it is difficult to describe some morphologies with certainty.

4 | DISCUSSION

4.1 | Taxonomic identity

The new skull has many diagnostic features that correlate with the Dicerorhini group, including a large terminal nasal horn boss and a large frontal horn boss, broad and long nasal bone, slightly reduced lingual cingulum of the upper premolars, weak metacone rib of P2–P3, constricted protocone of the upper molars, and presence of the crista in the upper cheek teeth (Heissig, 1989, 1999). These features distinguish it from most other rhinocerotids. The subfamily Aceratheriinae has no large horn on either the nasal or frontal bones, and their upper cheek teeth have both anteroposterior constrictions. The subfamily Elasmotheriinae has ample cement surrounding its crown.

When compared with *Diceros*, *Ceratotherium*, and *Coelodonta*, the nasal horn boss of the new skull is relatively smaller and the anterior portion of the nasal bone is narrower than the posterior region, unlike the wide nasal bone of the former three groups (Heissig, 1989, 1999). The horn boss of the new skull is a single spherical rough area rather than two swellings on each side of the nasal bone in *Diceros* and *Ceratotherium*. This indicates a relatively smaller nasal horn, with a size close to *Dihoplus ringstroemi* and *Dicerorhinus sumatrensis* (Groves & Kurt, 1972; Ringström, 1924). *Gaindatherium* from the Middle-Late Miocene has a much longer horn boss that nearly occupies the entire nasal bone, and its domed area is at the middle part of the nasal bone, corresponding to a probably larger horn (Colbert, 1934). *Diaceratherium* and *Hoploaceratherium* from the Early Miocene and Middle Miocene have a small horn boss on the nasal bone, with a much narrower width of the nasal bone itself, less than one-third of the maximum dorsal proof width between the orbits (Heissig, 2012; Lu et al., 2021). In addition, the remaining part of the dorsal proof of the new skull is similar to *Dih. ringstroemi* and *Dic. sumatrensis*, as well as *Gaindatherium* (Colbert, 1934; Groves & Kurt, 1972; Ringström, 1924), suggesting a long and horned skull, but which is not as robust as *Coelodonta* and extant African rhinoceroses (Borsuk-Bialynicka, 1973; Groves, 1972; Hillman-Smith & Groves, 1994). These features of the skull demonstrate a close relationship between the new material and the group Dicerorhini, especially the well-known *Dihoplus*.

Dihoplus is first established for "*Rhinoceros*" *schleiermacheri* from the Late Miocene (MN9) of Eppelsheim, Germany (Brandt, 1878; Kaup, 1832). Given its similarities to *Dicerorhinus* in the skull horn, *Dihoplus* has been considered a junior synonym (Arambourg, 1959; Guérin, 1980; Heissig, 1989). Revalidation of this genus is accompanied by revision of *D. megarhinus*, *D. ringstroemi*, and *D. pikermiensis* (Giaourtsakis, 2003). *D. schleiermacheri* differs from the new materials in that it has a shallow nasal notch at the level of P2, enlarged incisors, and developed metacone rib of the upper premolars (Giaourtsakis & Heissig, 2004; Kaup, 1832). *D. pikermiensis* from the Late Miocene (MN12) is close to the new skull, with a retracted nasal notch and a nearly continuous lingual cingulum in the upper premolars; however, it is also less advanced in having a stronger metacone rib of the upper premolars (Geraads & Spassov, 2009; Heissig, 1999). These are two separate species.

The new specimen is close to *D. ringstroemi*. Its skull from the Late Miocene described by Ringström (1924) is well preserved, albeit lacking the upper teeth: the occipital part is high, the front part is domed, and the anterior third of the nasal bone extends downward and its tip is lower than its ventral edge; the posterior end of the nasal notch is at the same level as the infraorbital foramen, albeit the position relative to the cheek teeth is unknown due to missing teeth; the ventral part of the external pseudomeatus auditory is closed; the parietal crests are widely separated; and the nuchal face is wide. The skull from the Late Miocene Linxia Basin described by Deng (2006a) is well preserved but lacks premaxillae. In addition to the above-mentioned features, the skull revealed that the nasal notch is at the P4 level. Furthermore, it reveals important unknown features of the upper cheek teeth. These materials are similar to new skull in nearly all aspects of the skull and teeth: the arched nasal boss, deep nasal notch at the level of P4, expanded lingual cusps of the upper cheek teeth, developed parastyle and paracone rib of the upper cheek teeth, weak crochet of the upper cheek teeth, weak lingual cingulum of the upper premolars, and constricted lingual cusps of the upper molars (Deng, 2006a; Ringström, 1924). The only visible difference lies in the constriction of the protocone in M2 of the skull from the Linxia Basin, which is slightly weaker than that of the new teeth. On the other hand, although in the deep wear stage, the lingual cingulum remains in P4 from the Linxia Basin, but is not visible in P2 and P3, probably has been worn off. This is probably also true for the metacone rib; its presence in the upper premolars from the Linxia Basin is uncertain. Therefore, the new skull can be assigned to *D. ringstroemi*. In addition, the new skull first demonstrates that the well-preserved premaxillae of *D. ringstroemi* have a small incisor.

Ringström (1924) attributed ample skulls, mandibles, and postcranial bones to "*Dicerorhinus*" *orientalis*, which was found in the Late Miocene of Pikermi, Greece by Schlosser (1921). Lately, Arambourg (1959) noted the wide gap of size between materials described by Schlosser (1921) and Ringström (1924), established "*Dicerorhinus*" *ringstroemi* for "*Dicerorhinus*" *orientalis*. Geraads (1988) revised "*Dicerorhinus*" *orientalis* from Greece by Schlosser (1921) to "*Dicerorhinus*" *pikermiensis* (Toula, 1906). When discussing rhinoceros from the Neogene (MN 11–12) of Greece, Giaourtsakis (2003) placed "*Dicerorhinus*" *ringstroemi* from China and "*Dicerorhinus*" *pikermiensis* into *Dihoplus*. This revision was later followed by Pandolfi et al. (2015).

Lately, Pandolfi et al. (2015, 2021) revised *D. ringstroemi* to "*Dihoplus*" *megarhinus* as a junior synonym and established a new genus to cover this species, *Pliorhinus*, *P. megarhinus*. There are many skulls of *Pliorhinus megarhinus* from western Europe (de Christol, 1834; Guerin et al., 1969; Pandolfi et al., 2015). Based on the preserved part of these skulls, the difference lies in *Pliorhinus* or *P. megarhinus* is more advanced relative to *D. ringstroemi*: the nasal notch and infraorbital foramen are above the molar, deeper than the latter, which is at the P4 level; the nuchal part extends posteriorly over the occipital condyle, which is slightly anteriorly inclined in the latter. It is too cursory to refer *D. ringstroemi* to genus *Pliorhinus*.

In terms of rhinocerotine cheek teeth from the late Neogene, there are three obvious diagnostic features: reduction of the metacone rib in the upper premolars, absence of the lingual cingulum in the upper premolars, and absence of lingual cusp constriction in the upper molars (Heissig, 1989). These three features appear with a type of mosaic evolution coexisting in several genera. Among the materials referred to *P. megarhinus* (Pandolfi et al., 2015, 2021), the metacone rib and lingual cingulum of the upper premolars, and protocone constriction of M1 and M2 are variable, indicating a transitional situation of this species. However, it is an open question whether all these materials should be separated into independent species, defining a species in a more specific way. In fact, during the transition process of these structures from the Late Miocene to the Pliocene, the most helpful way to make a classification is to combine morphological comparison with the record of the biogeographic distribution.

On the other hand, the new skull from the Qin Basin and the skull from the Linxia Basin demonstrate that *D. ringstroemi* maintains the lingual cingulum and metacone rib in the upper premolars, and that protocone constriction in M1 and M2 coexist with the relatively shallower nasal notch (P4 level) and the anteriorly inclined nuchal part. This is at an early stage of the evolution of these features.

Currently, all materials of *D. ringstroemi* are from the Late Miocene and Pliocene of Shanxi, Henan, and Gansu in China, with skulls, mandibles, postcranial bones, and juvenile materials (Deng, 2006a; Ringström, 1924). *Dihoplus ringstroemi* is a valid and independent species, and is the only representative of this genus in East Asia. The above-mentioned evolutionary tendency of teeth, together with the shape of the skull, indicates *Dihoplus* is the ancestor of *Pliorhinus*.

4.2 | Stratigraphic correlation

Geologically, the Qin, Wuxiang, and Yushe basins are controlled by large-scale Taihang Mountains orogenesis and are located upstream of the Zhuozhang drainage system (Li et al., 2015; Ye et al., 1987). The Yushe Basin is the most studied basin, with well-outcropped sections and numerous fossils (Cao, 1980; Cao et al., 1998; Cao & Wu, 1985; Qian et al., 2010; Qiu et al., 1987; Tedford et al., 2013). In the Yushe Basin, Cenozoic sediments have been divided into four formations through basal upward: the Late Miocene Mahui Formation, Early Pliocene Gaozhuang Formation, Late Pliocene Mazegou Formation, and Pleistocene Haiyan Formation.

The Mahui Formation in the Yushe Basin was deposited primarily as fluvial facies and consisted mainly of boulder conglomerates and cross-bedded sands. The upper part is occupied by interbedded sands, muds, and marls (Tedford et al., 2013). However, it remains uncertain whether thin claystones and flaggy limestones of the upper elements of the Mahui Formation represent basin-wide lacustrine phases or floodplain ponds. In the eastern part of the Yuncu subbasin, the Gaozhuang Formation overlies wiht angular unconformity on the Mahui Formation. The Gaozhuang Formation is well outcropped in the Yuncu subbasin, with three distinct units: lower Taoyang members, middle Nanzhuanggou members, and upper Culiugou members. The thick marl sediment of the lacustrine condition that characterizes the Gaozhuang Formation is present in the Nanzhuanggou unit, which is overlaid with cross-bedded sand and more oxidized violet color mudstone of the Culiugou member. In the Tancun subbasin, the marl deposit is thin and scattered. The Mazegou Formation in the Yuncu subbasin is characterized by thick mudstone and limestone, but rare coarse or pebbly sands, and the mudstone is darker in color than that of the Gaozhuang Formation. This sediment suggests a lateral-accreting system and is found only in the Yuncu subbasin.

The strata in the Qin Basin remain poorly known, particularly whether there is wide exposure of the Mahui Formation. Nevertheless, previous surveys have suggested that it is always exposed along the eastern part of the three basins. Two sections between the Qin and Wuxiang basins and one section southeast of the Qin Basin were described by Teilhard de Chardin and Young (1933): thick boulder conglomerates rest on the Triassic basement; North and westward into the basin are sandstone deposits with interbedded violet clays and limestone units. The new strata are consistent with those of the three sections in the interbedded sandstone and mudstone; however, the basal conglomerate in the new section is unknown. The conglomerate bed in the upper part of the new section was thick and marked a new deposition series. However, it is difficult to assign this new section to the Mahui Formation. Furthermore, in both the Yuncu and Zhangcun subbasins of the Yushe, elements of conglomerate, sandstone, and mudstone are iteratively deposited through the late Neogene with high frequency. Nevertheless, Tedford et al. (2013) noted that conglomerates or beds with cobbles and granules are more frequently present in the Mahui Formation than in the Gaozhuang Formation; however, the Mazegou Formation is dominated by mudstones or claystones. Considering the distribution of *Dihoplus ringstroemi* crossing through the Late Miocene to Pliocene, a tentative postulation of the new section in the Qin Basin corresponds to the Mahui Formation or Gaozhuang Formation.

AUTHOR CONTRIBUTIONS

Bao-Zhong Shi: Conceptualization, data curation, investigation, methodology, resources, visualization, writing – original draft, and writing – review and editing. **Shao-Kun Chen:** Fieldwork, methodology, data curation, and material preparation. **Tao Deng and Xiao-Kang Lu:** Project administration, supervision, and writing, review, and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no potential conflict of interest.

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REFERENCES

Arambourg, C. (1959). Vertébrés continentaux du Miocène supérieur de l'Afrique du Nord. *Service de la Carte géologique de l'Algérie, Mémoire*, *4*, 5–159.

Borsuk-Bialynicka, M. (1973). Studies on the Pleistocene rhinoceros *Coelodonta antiquitatis* (Blumenbach). *Palaeontologia Polonica*, *29*, 1–148.

Brandt, J. F. (1878). Mittheilungen uber die Gattung Elasmotherium, besonders den Schadelbau derselben. *Mémoires de l'Académie Impériale des Sciences de Saint Pétersbourg Série 7 (26)*, *6*, 1–36.

Cao, J. (1980). A study of Cenozoic strata and depositional environment of the Taigu-Yushe-Wuxiang area, Shanxi. *Quaternaria Sinica*, *4*, 77–82.

Cao, J., & Cui, H. (1989). Research of Pliocene flora and paleoenvironment of Yushe Basin on Shanxi plateau, China. *Scientia Geologica Sinica*, *4*, 367–375.

Cao, J., Huang, R., Shi, N., & Luo, Y. (1998). Late Pliocene lacustrine varves and its environmental information and time mark record. *Quaternary Science*, *4*, 351–360.

Cao, J., & Wu, R. (1985). The characteristics of sediments and landform evolution of the late Cenzoic down-warped basin in Yushe and Wuxiang district, Shansi. *Quaternaria Sinica*, *6*, 77–82.

Colbert, E. H. (1934). A new rhinoceros from the Siwalik beds of India. *American Museum Novitates*, *749*, 1–13.

de Christol, J. (1834). Recherches sur les caracteres des grandes especes de rhinoceros fossiles. *Annales des Sciences Naturelles*, *4*, 44–112.

Deng, T. (2006a). Neogene rhinoceroses of the Linxia Basin (Gansu, China). *Courier Forschungsinstitut Senckenberg*, *256*, 43–56.

Deng, T. (2006b). Chinese neogene mammal biochronology. *Vertebrata PalAsiatica*, *44*, 143–163.

Deng, T., Hou, S. K., Wang, T. M., & Mu, Y. Q. (2010). The Gaozhuang stage of the continental Pliocene series in China. *Journal of Stratigraphy*, *34*, 225–240.

Deng, T., Qiu, Z. X., Wang, B. Y., Wang, X. M., & Hou, S. K. (2013). Late Cenozoic biostratigraphy of the Linxia Basin, northwestern China. In X. M. Wang, L. J. Flynn, & M. Fortelius (Eds.), *Fossil mammals of Asia: Neogene biostratigraphy and chronology* (pp. 243–273). Columbia University Press.

Deng, T., Wang, W. M., Yue, L. P., & Zhang, Y. X. (2004). New advances in the establishment of the Neogene Baode stage. *Journal of Stratigraphy*, *28*, 41–47.

Geological Bureau of Shanxi Province. (1985). *Late Cenozoic stratigraphy of Shanxi Province*. Geological Publishing House (in Chinese).

Geraads, D. (1988). Révision des Rhinocerotinae (Mammalia) du Turolien de Pikermi: comparaison avec les formes voisines. *Annales de Paléontologie*, *74*, 13–41.

Geraads, D., & Spassov, N. (2009). Rhinocerotidae (Mammalia) from the late Miocene of Bulgaria. *Palaeontographica Abteilung A*, *287*, 99–122.

Giaourtsakis, I. X. (2003). Late Neogene Rhinocerotidae of Greece: Distribution, diversity and stratigraphical range. In J. W. F. Reumer & W. Wessels (Eds.), *Distribution and migration of tertiary mammals in Eurasia - A volume in honour of Hans de Bruijn, Deinsea* (Vol. 10, pp. 235–253).

Giaourtsakis, S. X., & Heissig, K. (2004). On the nomenclatural status of *Aceratherium incisivum* (Rhinocerotidae, Mammalia). Proceeding of 5th international symposium eastern Mediterranean geology, Thessaloniki, Greece, 1, 314–317.

Groves, C. P. (1972). Ceratotherium simum. *Mammalian species*, *6*, 1–6.

Groves, C. P., & Kurt, F. (1972). *Dicerorhinus sumatrensis*. *Mammalian species*, *21*, 1–6.

Guérin, C. (1980). Les rhinocéros (Mammalia, Perissodactyla) du Miocène terminal au Pléistocène supérieur en Europe occidentale: comparaison avec les espèces actuelles. *Documents du Laboratoire de Géologie de la Faculté Des Sciences de Lyon*, *79*, 1–1182.

Guerin, C., Ballesio, R., & Meon-Vilain, H. (1969). Le *Dicerorhinus megarhinus* (Mammalia, Rhinocerotidae) du Pliocene de Saint-Laurent-des-Arbres (Gard). *Documents du Laboratoire de Géologie de la Faculté Des Sciences de Lyon*, *31*, 55–145.

Heissig, K. (1989). Rhinocerotidae. In D. R. Prothero & R. M. Schoch (Eds.), *The evolution of perissodactyls* (pp. 399–417). Oxford University Press.

Heissig, K. (1999). Family Rhinocerotidae. In G. E. Rössner & K. Heissig (Eds.), *The Miocene land mammals of Europe* (pp. 175–188). Verlag Dr. Friedrich Pfeil.

Heissig, K. (2012). Les Rhinocerotidae (Perissodactyla) de Sansan. In S. Peigné & S. Sen (Eds.), *Mammifères de Sansan* (pp. 317–485). Muséum National d'Histoire Naturelle.

Hillman-Smith, K., & Groves, C. P. (1994). Diceros bicornis. *Mammalian species*, *455*, 1–8.

Kaup, J. J. (1832). Über *Rhinoceros incisivus* Cuvier und eine neue art *Rhinoceros schleiermacheri*. *Isis von Oken*, *1832*(8), 898–904.

Li, S., Guo, L., Xu, L., Somerville, I. D., Cao, X., Yu, S., Wang, P., Suo, Y., Liu, X., & Zhao, S. (2015). Coupling and transition of Meso–Cenozoic intracontinental deformation between the Taihang and Qinling Mountains. *Journal of Asian Earth Sciences*, *114*, 188–202.

Lu, X., Cerdeño, E., Zheng, X., Wang, S., & Deng, T. (2021). The first Asian skeleton of *Diaceratherium* from the early Miocene Shanwang Basin (Shandong, China), and implications for its migration route. *Journal of Asian Earth Sciences: X*, *6*, 100074. https://doi.org/10.1016/j.jaesx.2021.100074

Pandolfi, L., Gasparik, M., & Piras, P. (2015). Earliest occurrence of "*Dihoplus*" *megarhinus* (Mammalia, Rhinocerotidae) in Europe (late Miocene, Pannonian Basin, Hungary): Palaeobiogeographical and biochronological implications. *Annales de Paléontologie*, *101*, 325–339.

Pandolfi L, Pierre-Olivier A, Bukhsianidze M, Lordkipanidze D, Rook L. 2021. Northern Eurasian rhinocerotines (Mammalia, Perissodactyla) by the Pliocene–Pleistocene transition: phylogeny and historical biogeography. *Journal of Systematic Palaeontology*, *19*, 1031–1057.

Pei, W. Z., Zhou, M. Z., & Zheng, J. J. (1963). *Chinese Cenozoic Erathem* (pp. 1–31). Science Press.

Qian, C., Han, J. E., Yu, J., He, C. G., Zhu, D. G., Shao, Z. G., Meng, X. G., & Wang, J. (2010). The evolution of the depositional environment along the Gaozhuang formation section in Yushe Basin, Shanxi Province. *Geology in China*, *37*, 1607–1617.

Qiu, Z. X., Huang, W. L., & Guo, Z. H. (1987). The Chinese hipparionine fossils. *Palaeontologia Sinica, New Series*, *C25*, 1–243 (in Chinese with English summary).

Qiu, Z. X., & Qiu, Z. D. (1995). Chronological sequence and subdivision of Chinese Neogene mammalian faunas. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *116*, 41–70.

Qiu, Z. X., & Wang, B. Y. (2007). Paracerathere fossils of China. *Palaeontologia Sinica, Series C*, *29*, 1–396.

Ringström, T. (1924). Nashorner des *Hipparion* Fauna Nord Chinas. *Palaeontologia Sinica, Series C*, *1*(4), 1–156.

Schlosser, M. (1921). Die Hipparionen fauna von Veles in Mazedonien. *Abhandlungender Bayerischen Akademie der Wissenschaften*, *29*, 1–55.

Sisson, S. B. (1953). *The anatomy of the domestic animals* (4th ed., pp. 1–972). Saunders W. B. Company.

Tedford, R. H., Qiu, Z. X., & Flynn, J. L. (2013). *Late Cenozoic Yushe Basin, Shanxi Province, China: Geology and fossil mammals. History, Geology and Magnetostratigraphy* (Vol. I, pp. 1–109). Springer.

Teilhard de Chardin, P., & Young, Z. J. (1933). The late Cenozoic formation of S. E. Shansi. *Bulletin of the Geological Society of China*, *12*, 207–248.

Toula, F. (1906). *Das Gebiss und Reste der Nasenbeine von Rhinoceros (Ceratorhinus Osborn) hundsheimensis* (Vol. 20, pp. 1–38). *Abhandlungen der k.k*. Geologischen Reichsanstalt.

Ye, H., Zhang, B., & Mao, F. (1987). The Cenozoic tectonic evolution of the great North China: Two types of rifting and crustal necking in the great North China and their tectonic implications. *Tectonophysics*, *133*, 217–227.

Zdansky, O. (1923). Fundorte der *Hipparion* Fauna um Pao-Te-Hsien in NW-Shansi. *Bulletin of the Geological Survey of China*, *5*, 69–81.

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