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First record of Early Cretaceous pterosaur from the Ordos Region, Inner Mongolia, China

Shu-an Ji[a, b,*]

[a] *Institute of Geology, Chinese Academy of Geological Sciences, Beijing* 100037, *China*
[b] *Key Laboratory of Stratigraphy and Palaeontology, Ministry of Natural Resources, Beijing* 100037, *China*

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A B S T R A C T

A new dsungaripterid pterosaur, *Ordosipterus planignathus* gen. et sp. nov., is established on the incomplete articulated lower jaws from the Lower Cretaceous Luohandong Formation in Otog Qi, Ordos Region, Inner Mongolia, China. It differs from other dsungaripterids mainly by having broad and low dentary at and just behind the mandibular symphysis, flat dentary dorsal plane forming the distinct lateral ridge with the curved dentary lateral side, and lower alveoli arranged along the dentary dorsolateral margin with wide spacing that increases from rostral to caudal. It represents the first diagnostic pterosaur from the Ordos Region in Inner Mongolia, and further enlarges the geographical distribution of the family Dsungaripteridae from northwestern China (together with western Mongolia) to central North China.

1. Introduction

Ordos Region is located in the southwestern Inner Mongolia, North China and outlined to the west, north and east by a prominent northward bend of the Yellow River. The Early Cretaceous terrestrial deposits are widely exposed in this region, yielding abundant fossil tetrapods such as turtles (Brinkman DB and Peng JH, 1993a, 1993b; Tong HY and Brinkman DB, 2013; Ji SA and Chen XY, 2018), choristoderes (Brinkman DB and Dong ZM, 1993), crocodiles (Wu XC et al., 1994, 1996), sauropods (Hou YD et al., 2017), theropods (Russell DA and Dong ZM, 1993), stegosaurs (Dong ZM, 1993c; Hou YD and Ji SA, 2017), ankylosaurs (Ji SA et al., 2016), psittacosaurs (Russell DA and Zhao XJ, 1996), enantiornithine birds (Dong ZM, 1993b; Hou LH, 1994; Li JJ et al., 2008) and mammals (Godefroit P and Guo DY, 1999).

Pterosaurs were a special group of the Mesozoic flying reptiles. Those remains of the named pterosaur taxa have been uncovered in many places across northern China, e.g., Xinjiang Uygur Autonomous Region, Gansu Province, Liaoning Province and its neighboring regions (Lü JC et al., 2006; Wu XC et al., 2017). In the late 1980s, a team of the Sino-Canadian Dinosaur Project carried out field expeditions in the Ordos Region of Inner Mongolia, and excavated rich fossil tetrapods from the Early Cretaceous deposits. In several papers concerning the turtles and dinosaurs published in 1993, only pterosaur bones were mentioned (Brinkman DB and Peng JH, 1993a; Russell DA and Dong ZM, 1993; Dong ZM, 1993c). But no pterosaur specimens have been presented from this region up to now by the Sino-Canadian Dinosaur Project. Recently, the author has discovered many new vertebrate fossils from the Ordos Region of Inner Mongolia, including a pterosaur bone of incomplete articulated lower jaws (Ji SA et al., 2017). This pterosaur material represents the first diagnostic pterosaur from the Ordos Region of Inner Mongolia, further enriches the Early Cretaceous vertebrate fauna there. In the present paper, this pterosaur will be systematically described and discussed.

2. Geographic and geological setting

The pterosaur specimen was collected at Xinzhao village, roughly 40 km north of the town of Otog Qi, southwestern Inner Mongolia, China (Fig. 1). This region is also the northern part of the large Mesozoic continental Ordos Basin in the center of North China.

* Corresponding author: *E-mail address*: jishu_an@sina.com (Shu-an Ji).

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The Early Cretaceous strata are widely exposed in western areas of Ordos Region, especially in Otog Qi and Hanggin Qi. The lithostratigraphic unit here is called the Zhidan Group, which has been generally used for the Early Cretaceous terrestrial deposits in Ordos Basin (Bureau of Geology and Mineral Resources of Inner Mongolia Autonomous Region, 1996; Zhang H et al., 2008). It comprises a lower part of red, purplish to bluish mudstones and sandstones and an upper part of greyish-green to reddish-orange cross-bedded sandstones and siltstones. The Zhidan Group consists of five formations in ascending order: Yijun, Luohe, Huanhe, Luohandong and Jingchuan formations. Only Huanhe, Luohandong and Jingchuan formations have the large area of outcrops in Otog Qi and Hanggin Qi, and produce vertebrate fossils. Among the known fossil sites, Laolonghuozi and Chabu are most important (Fig. 1), with representative vertebrate faunas from Luohandong Formation and Jingchuan Formation respectively.

The new pterosaur locality, Xinzhao village in Otog Qi, is roughly situated at the middle area between the Laolonghuozi and Chabu sites. The lower part of Luohandong Formation and the upper part of Huanhe Formation are well exposed here; and the former conformably overlies the latter. The upper part of Huanhe Formation consists mainly of the purplish-red thick-bedded coarse sandstones with argillaceous sandstones, with well-developed cross-beddings. The strata of the lower part of Luohandong Formation comprise grey, greyish-yellow, or greyish-purple sandstones or coarse sandstones, with cross-beddings in some layers. The pterosaur bone described in this paper was collected from the lower part of Luohandong Formation. A few fragmentary turtle shields, a nearly complete theropod tibia and several unidentified bones were also found in the same formation.

The Zhidan Group is one of the typical lithostratigraphic units bearing the endemic "*Psittacosaurus* Fauna" throughout the Early Cretaceous basins of central and eastern Asia including the northern China, Mongolia, Siberia and Japan (Dong ZM, 1993a; Lucas SG, 2006).

3. Systematic description

Order Pterosauria Kaup, 1834

Suborder Pterodactyloidea Plieninger, 1901

Family Dsungaripteridae Young, 1964

Genus *Ordosipterus* gen. nov.

Type species. *Ordosipterus planignathus* gen. et sp. nov.

Etymology. Ordos, referring to the Ordos Region of Inner Mongolia; pterus (Greek), meaning wing, the common suffix of pterosaur taxa.

Diagnosis. As for the type and only species.

Ordosipterus planignathus gen. et sp. nov.

Etymology. Plani- (Latin) and gnathus (Greek), meaning flat and jaw, referring to the flat lower jaws of the new pterosaur.

Holotype. IG V13-011 (Institute of Geology, Chinese Academy of Geological Sciences), anterior portion of articulated lower jaws with a partial tooth and several alveoli (Figs. 2, 3).

Type locality and horizon. Xinzhao, Otog Qi, Inner Mongolia Autonomous Region, China; lower part of Luohandong Formation, Zhidan Group, Lower Cretaceous.

Diagnosis: Distinguished from other dsungaripterids in having broad and low dentary at and just behind the mandibular symphysis, a weak ventral median ridge present at

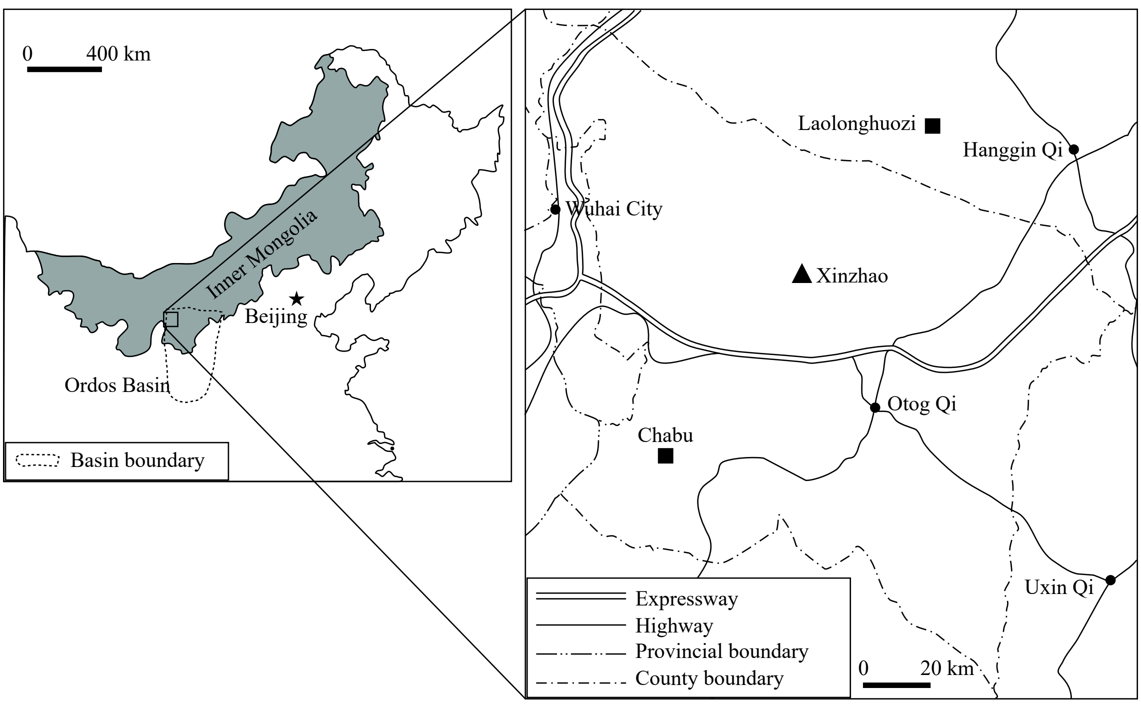

Fig. 1. Sketch map showing the new Early Cretaceous pterosaur locality (▲) in Otog Qi, Inner Mongolia, China. ■–other representative vertebrate fossil sites in Otog Qi and Hanggin Qi.

Fig. 2. Holotype (IG V13-011) of *Ordosipterus planignathus* gen. et sp. nov., incomplete articulated lower jaws. a–dorsal view; b–left lateral view; c–ventral view.

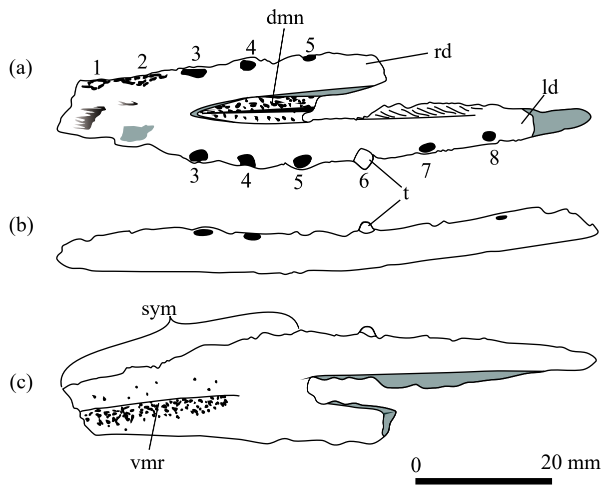

Fig. 3. Line drawings of the holotype (IG V13-011) of *Ordosipterus planignathus* gen. et sp. nov. a–dorsal view; b–left lateral view; c–ventral view. dmn–dorsal median notch; ld–left dentary; rd–right dentary; sym–mandibular symphysis; t–tooth crown; vmr–ventral median ridge; 1–8–1st to 8th preserved dentary alveoli.

least at the middle portion of symphysis, flat dentary dorsal plane forming the distinct lateral ridge with the curved dentary lateral side, lower alveoli arranged along the dentary dorsolateral margin with wide spacing that increases from rostral to caudal, the distance between two adjacent alveoli about 1.5 times to 3 times the rostrocaudal diameter of the front alveolus.

Description: The specimen consists of the anterior portion of articulated lower jaws, with partial rami of both dentaries. The rostral tip of the mandibular symphysis is missing (Figs. 2, 3). The preserved segments of the left and right dentaries measure 77 mm and 45 mm long respectively.

The anterior parts of both dentaries are completely fused into the long mandibular symphysis that is about 33 mm long in preservation. The angle between the lateral margins of symphysis is about 18°. The dentary dorsal surface is wide and flat, forming the distinct lateral ridge with the curved dentary lateral side. Dorsally, a narrow V-shaped notch is present at the midline of the posterior part of symphysis. The transverse cross section of the dentary ventral outline shows the wide curvature, with no remarkable margin between the ventral and lateral sides. There exists a weak median ridge along the midline at the ventral surface of symphysis, which ends ahead of the symphysis' caudal point. In the lateral view, both dorsal and ventral margins of the dentary are nearly parallel. The height at the caudal end of symphysis is about 6.0 mm, slightly less than the dorsal width of either dentary (6.5 mm) at this point. The posterior portion of dentary is slightly curved upwards from the position of the sixth preserved alveolus (tooth).

A row of alveoli are present along the outer margin of either dentary dorsal plane. Only eight preserved alveoli are identified on the left dentary, with posterior six ones clear in preservation. But the exact number of dentary teeth remains uncertain owing to the lack of rostral and caudal ends of this bone. The mandibular symphysis gives out anterior five preserved teeth pairs. The alveoli are bulbously expanded as seen in some dsungaripterids. The individual alveoli are slightly elongated rostrocaudally. The dentation at the symphysis is almost completely straight, while the following alveolar series slightly bend to midline.

Only partial tooth crown of the sixth preserved left tooth remains at its original position. It seems that the tooth crown is short and blunt.

On the left dentary, the middle four well-preserved alveoli are somewhat larger than the following two alveoli in diameter. These alveoli are widely spaced, with the spacing about 1.54 times to 3.13 times the rostrocaudal diameter of any individual alveolus just in front (Table 1). Such spacing increases gradually from rostral to caudal.

Table 1. Measurements of diameter and spacing of the preserved dentary alveoli (mm).

Preserved alveolus	3	4	5	6	7	8
Rostrocaudal diameter	3.0 (l)	2.4 (r)	2.9 (l)	2.7^e(l)	2.2 (l)	2.0^e(l)
Spacing following	4.6^e(r)	5.1^e(l)	5.5 (l)	6.2 (l)	6.9 (l)	–
Spacing / diameter	1.54	2.13	1.89	2.27	3.13	–

Notes: l–left side; r–right side; ^{e}–estimated values.

4. Comparison and discussion

The pterosaurs of family Dsungaripteridae are a distinct group as showed in some analyses (Bennett SC, 1989, 1994; Kellner AWA, 2003; Unwin DM, 2003). Up to now, several genera and species from Asia and South America have been generally included within Dsungaripteridae: *Dsungaripterus weii* (Young CC, 1964, 1973), *Noripterus complicidens* (Young CC, 1973) ("*Phobetor*" *parvus*; Bakhurina NN, 1986), *Lonchognathosaurus acutirostris* (Maisch NW et al., 2004), *Domeykodactylus ceciliae* (Martill DM et al., 2000), and possible *Puntanipterus globosus* (Bonaparte JF and Sanchez TM, 1975). In spite of incompleteness, the new specimen described herein (IG V13-011) can be assigned to

Dsungaripteridae by having bulbously expanded, widely spaced alveoli on the lower jaw.

The toothless jaw tips are apomorphies of Dsungaripteridae (Kellner AWA, 2003; Unwin DM, 2003; Lü JC et al., 2009). The rostral tip of the mandibular symphysis is missing in this new specimen, showing no evidence for the absence or presence of teeth at the anterior portion of jaws. The alveoli are bulbously expanded in the new specimen, as in *Dsungaripterus* (Young CC, 1964, 1973; Lü JC et al., 2009) and *Domeykodactylus* (Martill DM et al., 2000), which have been noted as autapomorphy for Dsungaripteridae. But the degrees of prominence of the alveolar protuberances are different in these taxa. The alveolar spacing is generally wide in all dsungaripterids, giving additional support for the inclusion in Dsungaripteridae of the Ordos pterosaur. Kellner noted that the main features of Dsungaripteridae also showed by the sub-circular or oval tooth bases (Kellner AWA, 2003). The oval alveoli are present in the new specimen, *Dsungaripterus* (Young CC, 1964, 1973), *Noripterus* (Young CC, 1973; Lü JC et al., 2009), and *Lonchognathosaurus* (Maisch NW et al., 2004).

Most preserved portions of dentaries including symphysis are very low, with broad and flat dorsal surfaces in the new pterosaur. In this aspect, it is remarkably different from other dsungaripterids. Thus, a new genus and species, *Ordosipterus planignathus* is established (Fig. 4).

Dsungaripterus is the large pterosaur in northwestern China and western Mongolia (Young CC, 1964, 1973; Lü JC et al., 2009; Li DL and Ji SA, 2010), much larger than *Ordosipterus* based on the dimension of their lower jaws. The lower jaw of *Ordosipterus* is low and broad at the caudal point of mandibular symphysis, and the ventral margin is almost parallel to the dorsal margin. *Dsungaripterus* possesses the tall and narrow mandibular ramus, while the caudal part of symphysis is pachyostosed with prominent ventral margin as in the holotype (Young CC, 1964) and another specimen (Young CC, 1973; Li DL and Ji SA, 2010). In comparison with those in *Dsungaripterus*, the dentary alveoli of *Ordosipterus* are proportionally smaller, and more widely spaced. The differences between these two taxa are distinct.

Fig. 4. Restoration figure *Ordosipterus planignathus* gen. et sp. nov.

The original specimens of *Noripterus* were recorded from Urho, Xinjiang, China (Young CC, 1973). The dsungaripterids labeled as *Dsungaripterus parvus* or “*Phobetor*” *parvus* from Tatal, western Mongolia (Bakhurina NN, 1982, 1986; Bakhurina NN and Unwin DM, 1995; Unwin DM and Bakhurina NN, 2000) have been considered a junior synonym of *Noripterus complicidens* (Lü JC et al., 2009). *Ordosipterus* differs mainly from *Noripterus* in that *Noripterus* has little evidence for the bulbously expanded alveoli (Young CC, 1973), while *Ordosipterus* bears the clearly bulbously expanded lower alveoli. The dentary dorsal surface of *Noripterus* is relatively narrow and prominent, also differing from the wide and flat dorsal plane of the lower jaw in *Ordosipterus*. The lower tooth row in *Noripterus* lines the top of dentary dorsal surface longitudinally, but the tooth row is arranged along the outer margin of dentary dorsal plane in *Ordosipterus*. Other remarkable difference is that there exists a deep sagittal groove on the dorsal surface of the mandibular symphysis in *Noripterus*, but only a narrow V-shaped notch is present at the midline of the posterior dorsal part of symphysis in *Ordosipterus*.

Only known by the anterior part of skull, *Lonchognathosaurus* (Maisch NW et al., 2004) is very difficult to directly compare to *Ordosipterus*. In the well-preserved specimens of *Dsungaripterus* (Young CC, 1964, 1973; Li DL and Ji SA, 2010), it seems that both upper and lower jaws have a similar tooth and alveolar morphology. Such case is also observed in *Noripterus* (Bakhurina NN and Unwin DM, 1995; Lü JC et al., 2009). Thus the dental differences between one upper jaw and another lower jaw would be used as an evidence for distinguishing different taxa. The lower alveoli in *Ordosipterus* and upper alveoli in *Lonchognathosaurus* are all slightly elongated rostrocaudally. The spacing of the alveoli is always larger than the alveolar rostrocaudal diameter, and increases from rostral to caudal in both taxa. The ratio of spacing to alveolar diameter in *Ordosipterus* is comparatively greater than that of *Lonchognathosaurus*. The alveoli are bulbously expanded in *Ordosipterus*, while the alveoli are not in *Lonchognathosaurus*. These characters make the two genera to be easily distinguished.

Domeykodactylus is largely diagnosed on a partial low jaw from Lower Cretaceous of Chile, South America (Martill

DM et al, 2000). *Ordosipterus* differs from *Domeykodactylus* in that the former possesses widely spaced lower alveoli while the latter has small and closely spaced mandibular teeth. Moreover, the dental alveolar borders are relatively more expanded in *Domeykodactylus* than in *Ordosipterus*.

It is difficult to compare *Ordosipterus* with *Puntanipterus*, which was described only on a single tibia with articulated fibula (Bonaparte JF and Sanchez TM, 1975) and later referred to Dsungaripteridae (Galton P, 1980). Other putative dsungaripterids from East Africa and South America "*Pterodactylus*" *brancai* (Galton P, 1980), "*Santanadactylus*" *spixi* (Bennett SC, 1989, 1994) need further study in respect of their diagnostic features and systematic relationships, thus any comparison with *Ordosipterus* is insignificant.

Huanhepterus quingyangensis is the first pterosaur reported from the Early Cretaceous Zhidan Group in the Ordos Basin, and is grouped in the family Ctenochasmatidae (Dong ZM, 1982). It was collected from the Huanhe Formation at Sanshilipu site in Qingyang, eastern Gansu Province. Located in the southern area of the Ordos Basin, Qingyang is more than 400 km south to Otog Qi, Inner Mongolia. *Huanhepterus* differs from *Ordosipterus* by larger size, having very long, pointed and tightly packed teeth in the front section of jaw.

Since the establishment of *Dsungaripterus weii* in 1964, total four dsungaripterid taxa have been revised and confirmed to exist in northern China and Mongolia. They are *Dsungaripterus weii*, *Noripterus complicidens*, *Lonchognathosaurus acutirostris* and *Ordosipterus planignathus*. Both *Dsungaripterus* and *Noripterus* were known from Urho (northwestern Junggar Basin, Xinjiang, China) (Young CC, 1964, 1973) and Tatal (western Mongolia) (Bakhurina NN, 1982, 1986; Bakhurina NN and Unwin DM, 1995; Unwin DM and Bakhurina NN, 2000; Lü JC et al., 2009), giving evidence of the coexistence of these two pterosaurs. At Delunshan in northwestern Junggar Basin, about 50 km northeast to Urho, a fragmentary tibia and nearly complete pes were reported to be assigned to *Dsungaripterus* (Dong ZM, 1973). At Wucaiwan of eastern Junggar Basin (Li DL and Ji SA, 2010), only *Dsungaripterus* was discovered. The author believes that it is most possible to find *Noripterus* in the future. At Liuhonggou near Urumqi, southern Junggar Basin, the finding of *Lonchognathosaurus* enriches our knowledge of the composition and distribution for the dsungaripterid pterosaurs (Maisch NW et al., 2004). It appears that the Junggar Basin (northwestern China), together with the adjacent Tatal region (western Mongolia), is the geographical center of the dsungaripterid distribution (Fig. 5).

In addition, more possible dsungaripterid material was also reported from northern Xinjiang, western Gansu Province and Shandong Province from the west to the east of northern China. (1) In 1964, Young CC tentatively referred a tibia with a fused fibula from the Lower Cretaceous of Changji, southern Junggar Basin in Xinjiang, to an ornithurine bird (Young CC, 1964). But later redescription and comparison suggested that the tibia and fibula should be interpreted as belonging to a dsungaripterid pterosaur (Buffetaut E, 1996). (2) At Chijin area, western Gansu Province, the bones of *Noripterus* cf. *N. complicidens* were reported from the Early Cretaceous Xinminbao Group (Niu SW, 1987). But no specimen has been described to further support the occurrence of the pterosaur group in this area. (3) In 1958, some fragments of limb bones were determined as? Pterosauria indet. (Young CC, 1958). They were known in association

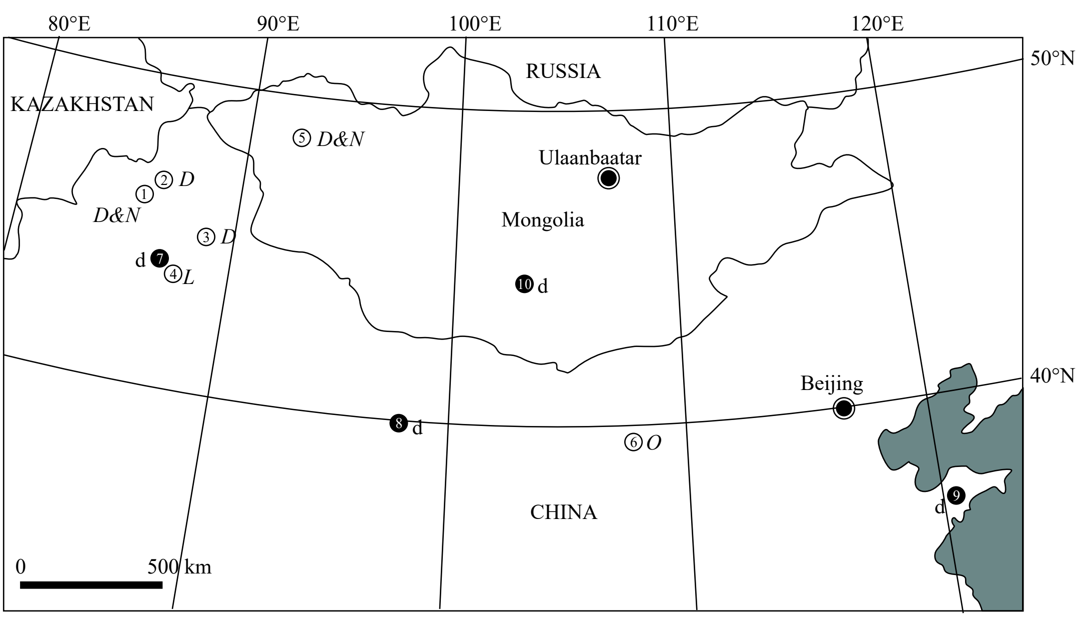

Fig. 5. Geographical distribution of dsungaripterid pterosaurs in northern China and Mongolia. ①–Urho, northwestern Junggar Basin, Xinjiang, China; ②–Delunshan, northwestern Junggar Basin, Xinjiang, China; ③–Wucaiwan, eastern Junggar Basin, Xinjiang, China; ④–Liuhonggou, southern Junggar Basin, Xinjiang, China; ⑤–Tatal, western Mongolia; ⑥–Xinzhao, northern Ordos Basin, Inner Mongolia, China; ❼–Changji, southern Junggar Basin, Xinjiang, China; ❽–Chijin, western Gansu, China; ❾–Laiyang, eastern Shandong, China; ❿–Öösh, central Mongolia. *D–Dsungaripterus*; *L–Lonchognathosaurus*; *N–Noripterus*; *O–Ordosipterus*; d–undetermined Dsungaripteridae.

with *Psittacosaurus sinensis*, all from the Early Cretaceous Qingshan Formation in Laiyang, Shandong Province, eastern China. Later, these remains were identified further to the genus *Dsungaripterus* or its affinities (Young CC, 1964). All the specimens from the above three sites have been just known by limb bones, even fragmentary or undescribed. More featured material needs for the confirmation of the dsungaripterid existence in these areas.

A unique cervical vertebra from the Early Cretaceous beds at Öösh, central Mongolia was reported (Andres B and Norell MA, 2005). Comparison of this vertebra with other pterosaur corresponding bones suggested that it is likely to represent a dsungaripterid pterosaur. Similarly, it needs further evidence.

Ordosipterus is the newest convincible dsungaripterid taxon from the lower Cretaceous in Asia, and is of significance in biogeography. It remarkably enlarges the geographical distribution of this pterosaur group from northwestern China (together with western Mongolia) to central North China (Fig. 5).

During the Early Cretaceous, two separate dinosaur faunas were identified in China and Mongolia: The northern fauna characterized by the presence of *Psittacosaurus* and common association of pterosaurs, and the southern fauna distinguished by the absence of psittacosaurs (Dong ZM, 1993a). Rich *Psittacosaurus* are widely distributed in many regions throughout the northern China, Mongolia, and Siberia and probably Japan (Lucas SG, 2006). Besides *Psittacosaurus*, pterosaurs are also present in many regions. At Urho and Delunshan, northwestern Junggar Basin in Xinjiang, the dsungaripterids and *Psittacosaurus xinjiangensis* coexisted (Sereno PC and Chao SC, 1988; Brinkman DB et al., 2001). At Tatal (western Mongolia) and Öösh (central Mongolia), there also occurred the *Psittacosaurus* material (Bakhurina NN and Unwin DM, 1995; Andres B and Norell MA, 2005). In Ordos Region where *Ordosipterus* was found, at least two species of *Psittacosaurus*, *P. neimongoliensis* and *P. ordosensis* have been identified (Russell DA and Zhao XJ, 1996). The discovery of new pterosaur *Ordosipterus* provides more evidence for the opinion that the endemic Psittacosaur-Pterosaur Fauna (or biogeographic realm) is reasonable to be recognized, which was widespread in eastern Asia (northern China, Mongolia, Siberia etc.) during the Early Cretaceous (Dong ZM, 1993a).

5. Conclusion

The Early Cretaceous *Ordosipterus planignathus* gen. et sp. nov. represents the first convincible pterosaur from the Ordos Region in Inner Mongolia, and the second pterosaur taxon from the Ordos Basin after *Huanhepterus quingyangensis* in Gansu Province. As a member of family Dsungaripteridae, *Ordosipterus* enlarges the geographical distribution of the dsungaripterid pterosaurs from the northwestern China (with western Mongolia) to central North China. This fossil further strengthens the opinion that the northern China and Mongolia belong to a unique and endemic dinosaur biogeographic realm featured by the presence of *Psittacosaurus* and pterosaurs during the Early Cretaceous period.

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