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Short communication

First definitive ankylosaurian dinosaur from the Cretaceous of Jilin Province, northeastern China

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ABSTRACT

We here report an ankylosaurian ilium from the Albian–Cenomanian Longjing Formation of Yanji City, Jilin Province, northeastern China. The diagnostic features allowing referral of this specimen to Ankylosauria include: an ilium rotated horizontally dorsal to the acetabulum with the primitive lateral surface facing ventrally; long and laterally divergent preacetabular process; and a shallow, cup-like acetabulum. This new specimen represents the first definitive ankylosaurian dinosaur from Jilin Province, and the easternmost ankylosaurian occurrence in China. The present discovery demonstrates the potential for future finds in the Longjing Formation, especially in the Longshan fossil beds of Yanji City, such as additional ankylosaurian or other dinosaur remains that might provide significant data on dinosaur evolution during the middle Cretaceous of eastern Asia.

1. Introduction

Ankylosauria is a clade of quadrupedal herbivorous armored dinosaurs, which are known from all continents with the exception of Africa (Vickaryous et al., 2004). The Asian ankylosaurian dinosaurs are known mostly from China and Mongolia (Arbour and Currie, 2016). In northeastern China, ankylosaurians have only been reported from Liaoning Province (Amiot et al., 2010; Dong, 2002; Han et al., 2014; Ji et al., 2014; Lü et al., 2007a; Xu et al., 2001; Yang et al., 2017).

Yanji City is located in the eastern part of Jilin Province, northeast to Liaoning Province (Fig. 1). The Tongfosi Formation in the west of Yanji has previously produced footprints of several dinosaurian groups, including theropods, ornithopods, and quadrupedal dinosaurs of uncertain affinities (Matsukawa et al., 1995; Xing et al., 2017). It was not until 2018 that dinosaur body fossils from Yanji were reported (Jin et al., 2018; Zhang et al., 2018). They were mainly discovered in the Longjing Formation of Longshan Mountain, in the south of Yanji, though one specimen was found from the Chaoyang River (Sun River in Jin et al., 2018), which is in the west of Yanji City.

In September 2017, IVPP, Fukui Prefectural University, and FPDM conducted a joint dinosaur expedition in Yanji, together with members of the Yanji Bureau of Land and Resources and the Yanbian Seismological Bureau. Dongchun Jin discovered one partial left ankylosaurian ilium in the east bank of the Chaoyang River during the expedition. It is the first definitive ankylosaurian dinosaur body fossil from Jilin Province.

1.1. Institutional abbreviations

AMNH, American Museum of Natural History, New York, New York, USA; CMN, Canadian Museum of Nature, Ottawa, Ontario,

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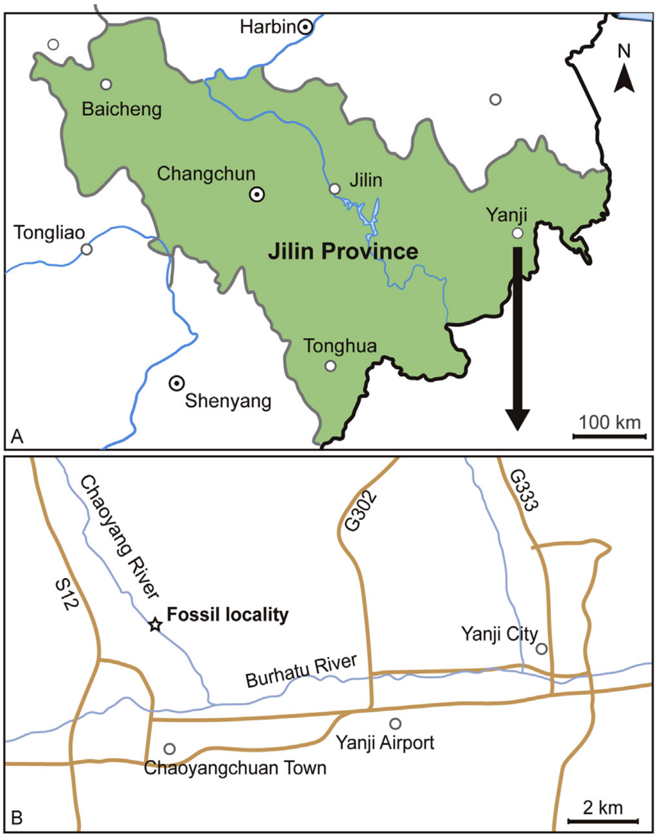

Fig. 1. Locality maps of the fossil locality. Map of Jilin Province showing the location of Yanji City (A), and Map of Yanji City with the fossil locality (marked by a star icon) (B).

Canada; FPDM, Fukui Prefectural Dinosaur Museum, Fukui, Japan; IVPP, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Beijing, China; NHMUK, Natural History Museum, London, United Kingdom; ZMNH, Zhejiang Museum of Natural History, Hangzhou, China.

2. Geological setting

The Yanji Basin is one of the largest terrestrial Mesozoic basins in the east of Jilin Province, with a total area of 1,500 km^2. The basin has well-exposed Mesozoic strata, especially Cretaceous ones, which include the Tongfosi, Dalazi, and Longjing formations in ascending order (Bureau of Geology and Mineral Resources of Jilin Province, 1988; Jin et al., 2018). The first body fossil was unearthed from the grey-green sandstone of the Longjing Formation, exposed on the east bank of the Chaoyang River, north of Chaoyangchuan Town (Fig. 1B).

The Longjing Formation, composed of purple-red and pale blue pebbled sandstone, and siltstone with nodular marl, is widely distributed around Chaoyangchuan, Mao'ershan, Longjing, and Jingu in the Yanji Basin. This formation reaches approximately 1,355 m in total thickness and is unconformably covered on the Dalazi Formation (Bureau of Geology and Mineral Resources of Jilin Province, 1988). The geological age of the Longjing Formation is still controversial. Although sometimes considered as the late Early Cretaceous in age (Bureau of Geology and Mineral Resources of Jilin Province, 1988; Sun and Zheng, 2000), it is usually placed in the early Late Cretaceous (Bureau of Geology and Mineral Resources of Jilin Province, 1988; Cui et al., 1994; Jin et al., 2018). Biostratigraphic evidence suggests that the Longjing Formation belongs to the early Late Cretaceous (Bureau of Geology and Mineral Resources of Jilin Province, 1988; Cui et al., 1994; Jin et al., 2018). Zircon and apatite fission track ages of the underlying Dalazi Formation are 100 Ma and 95 Ma, respectively (Li and Gong, 2008), which indicates that the geological age of the Longjing Formation should be younger, and thus dated to the Late Cretaceous. Jin et al. (2018) placed the Longjing Formation in the Cenomanian, based on these radiometric data and stratigraphic correlation. However, recent SIMS U–Pb zircon dating for the uppermost part of the Dalazi Formation in the Yanji Basin gave an age of 105.14 ± 0.37 Ma (Zhong et al., 2020). Moreover, recent CA-ID-TIMS zircon dating from the fossil beds of Longshan Mountain resulted in an age of 101.039 ± 0.061 Ma (Zhang et al., 2018). Both suggest an older age for the Dalazi and Longjing formations. Ostracod-based biostratigraphic data support an Albian–Cenomanian age for this formation (Zhong et al., 2020). Considering these recent researches, we regard a late Albian–Cenomanian age to be reasonable for the Longjing Formation in this study.

3. Systematic paleontology

Dinosauria Owen 1842
Ornithischia Seeley 1887
Thyreophora Nopcsa 1915
Ankylosauria Osborn 1923

Ankylosauria indet.

Material. IVPP V26052, an incomplete left ilium lacking its anterior and posterior ends (Fig. 2).
Locality and horizon. Chaoyang River, Chaoyangchuan Town, Yanji City, Jilin Province, northeast China. Longjing Formation (upper Albian–Cenomanian) (Bureau of Geology and Mineral Resources of Jilin Province, 1988; Jin et al., 2018; Zhang et al., 2018).

4. Description and comparisons

The ilium is incompletely preserved, missing its anterior and posterior ends (Fig. 2). The preserved anteroposterior length is 64.0 cm and the maximum mediolateral width is 25.5 cm. Despite the absence of all other materials, this specimen can be identified as an ankylosaurian because the ilium is one of the most distinctive elements in an ankylosaurian postcranial skeleton (Coombs, 1979). The ilium has several ankylosaur features that distinguish it from those of other dinosaurs, such as the ilium blade rotating horizontally dorsal to the acetabulum with the primitive lateral surface facing ventrally, long, and laterally divergent preacetabular process, and a shallow cup-like acetabulum (Coombs, 1978; Vickaryous et al., 2004).

The dorsal surface of the ilium is rough, with some irregular protuberances, pits, and longitudinal striations. In dorsal view, the ilium is relatively straight, and the lateral edge is slightly concave. The preacetabular process is long and compressed dorsoventrally, as in other ankylosaurians (Vickaryous et al., 2004). The portion dorsal to the acetabulum is domed, with the lateral portion of the ilium rotated slightly ventrally. In lateral view, the acetabulum is visible. The lateral edge of the preacetabular process is slightly curved ventrally towards anteriorly, as in most ankylosaurians. In contrast, the preacetabular process is curved strongly ventrally in some nodosaurids, such as *Mymoorapelta* (Kirkland and Carpenter, 1994). In ventral view, the ischial and pubic peduncles are prominent and continuous with each other as in most ankylosaurians, such as *Jinyunpelta* (Zheng et al., 2018), but unlike the well-separated peduncles in *Gargoyleosaurus* and *Mymoorapelta*

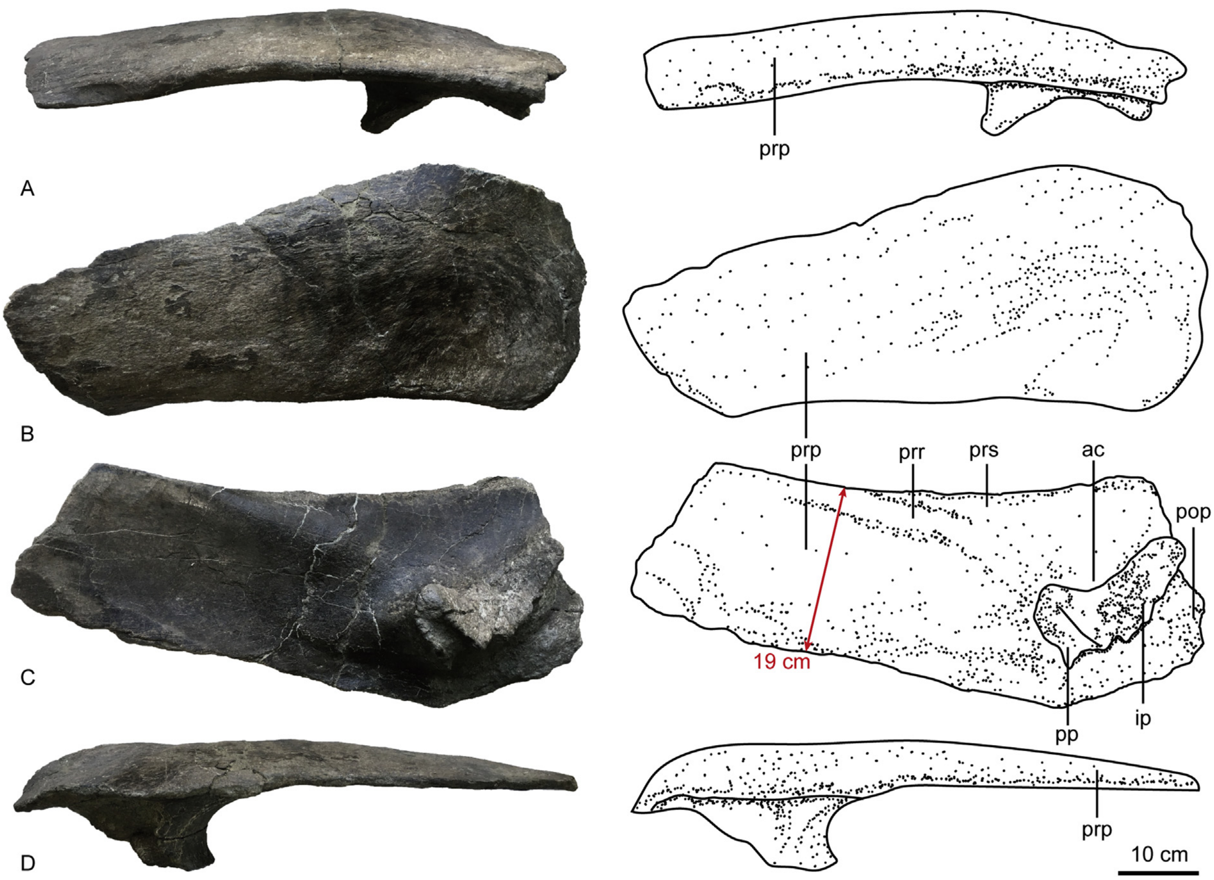

Fig. 2. Photographs (left) and drawings (right) of the ankylosaurian ilium (IVPP V26052) from Yanji in lateral (A), dorsal (B), ventral (C), and medial (D) views. Abbreviations: ac, acetabulum; ip, ischial peduncle; pop, postacetabular process; pp, pubic peduncle; prp, preacetabular process; prr, preacetabular ridge; prs, preacetabular shelf.

(Carpenter et al., 2013). The anterior portion of the peduncles is extended more ventrally and is more prominent than the posterior portion. The peduncles bound the acetabulum medially, which is shallow, cup-like and imperforate, as in other ankylosaurians (Vickaryous et al., 2004). Generally, this ventral surface bears a well-marked rounded longitudinal preacetabular ridge in ankylosaurians (Fig. 2: prr), which starts from the anterolateral corner of the iliac blade, becomes gradually fainter posteriorly, and merges with the ilium body anterolateral to the acetabulum. This ridge forms the lateral edge of the preacetabular process in the anterior portion, making the iliac blade thicker laterally than medially anterior to the acetabulum (Coombs, 1979). The preacetabular ridge is straight in ventral view, as in *Zhejiangosaurus* (Lü et al., 2007b), *Gargoyleosaurus* (Carpenter et al., 2013), *Sauropelta* (Coombs, 1978), *Chuanqilong* (Han et al., 2014), *Anodontosaurus* (AMNH 5245) (Arbour and Currie, 2013), and *Jinyunpelta* (Zheng et al., 2018). In contrast, the ridge is well-curved in *Crichtonpelta* (Arbour and Currie, 2016; Lü et al., 2007a), and *Pinacosaurus* cf. *grangeri* from Shandong (Buffetaut, 1995). The preacetabular ridge separates a narrow preacetabular shelf (Fig. 2: prs) from the main body of the preacetabular process, as in other ankylosaurians (Carpenter et al., 2013; Lü et al., 2007a; Lü et al., 2007b). The preacetabular process becomes slightly narrower anteriorly but is still relatively wide, like those of *Taohelong* (Yang et al., 2013), *Talarurus* (Maleev, 1956), and *Jinyunpelta* (Zheng et al., 2018). The process tapers gradually in contrast to those of some other ankylosaurians, such as *Gargoyleosaurus* (Carpenter et al., 2013), and *Gastonia* (Kirkland, 1998), in which the process tapers abruptly anterior to the acetabulum. In medial view, the medial edge is almost horizontal.

5. Discussion

The incomplete preservation of IVPP V26052 makes body size estimation difficult. The mediolateral breadth of the preacetabular process is approximately 19.0 cm at the point where the preacetabular ridge merges into the lateral edge (Fig. 2C). Although the medial edge of IVPP V26052 is somewhat damaged, this is common in ankylosaurian ilia due to their thin medial edge as seen in *Dyoplosaurus* (Arbour et al., 2009; Parks, 1924), *Anodontosaurus* (AMNH 5245) (Arbour and Currie, 2013), and *Jinyunpelta* (ZMNH M8961) (Zheng, 2018). The preserved mediolateral breadth of the preacetabular process of *Jinyunpelta* (ZMNH M8961) is approximately 15.8 cm (Fig. 3) (Zheng, 2018). The whole anteroposterior length of the ilium of ZMNH M8961 is 90.0 cm, similar to *Polacanthus* (NHMUK PV R175) (Pereda-Suberbiola, 1994; Raven et al., 2020). The estimated body lengths are 4.5–5 m for *Jinyunpelta* (Zheng, 2018) and 5–7 m for *Polacanthus* (Pereda-Suberbiola, 1994). The medial edge of the ilium of *Jinyunpelta* (ZMNH M8961) is already very thin, suggesting that the original form of the medial edge is mostly preserved and thus the width of the preacetabular process would not exceed 19.0 cm. The breadth of the preacetabular process at the similar position of *Polacanthus* (is approximately 21.0 cm, which is broader than IVPP V26052. *Euoplocephalus* (AMNH 5409) and *Edmontonia longiceps* (CMN 8531) also share a broader preacetabular process (Arbour and Currie, 2013; Coombs, 1979), and both of them have longer ilia than *Jinyunpelta* or *Polacanthus* (Arbour and Currie, 2013; Carpenter, 1990). The estimated body length of *Euoplocephalus* and *Edmontonia longiceps* are 5–6 m and 6–7 m, respectively (Arbour and Mallon, 2017; Vickaryous et

Fig. 3. The left ilium from Yanji (IVPP V26052) (A) and the left ilium of *Jinyunpelta* (ZMNH M8961) (B) in ventral views.

al., 2004). The small-bodied *Struthiosaurus languedocensis* has a maximum width of the preacetabular process reaching 12.5 cm and an estimated body length ranging between 2.5 and 3 m (Garcia and Suberbiola, 2003). Based on these comparisons, we estimate the body length of IVPP V26052 to be around 5–5.5 m, longer than *Jinyunpelta* but shorter than *Polacanthus*, *Euoplocephalus,* or *Edmontonia*. The estimated body length of the largest ankylosaurians exceeds 7 m, as in *Ankylosaurus* (6–10 m) (Arbour and Mallon, 2017) and *Cedarpelta* (7.5–8.5 m) (Carpenter et al., 2001). Other large-bodied ankylosaurians with a body length around 5–6 m include *Zuul* and ZPAL MgD I/113 (Ankylosaurinae indet.) (Arbour and Mallon, 2017), *Borealopelta, Sauropelta* (Brown et al., 2017), and *Scolosaurus* (Penkalski and Blows, 2013). Small-to medium-sized ankylosaurians with a body length around 3–5 m include *Gargoyleosaurus* (3–3.5 m) (Kilbourne and Carpenter, 2005), *Hungarosaurus* (4–4.5 m) (Ősi et al., 2019; Ősi and Makádi, 2009), *Pinacosaurus grangeri* (5 m) (Maryańska, 1977), *Pinacosaurus mephistocephalus* (3 m) (Godefroit et al., 1999), PIN 614 (3.6 m) and MPC 100/1305 (3.9 m) (both cf. *Pinacosaurus*), *Dyoplosaurus* (3.95–4.53 m), and *Anodontosaurus* (>4 m) (Arbour and Mallon, 2017). The small-sized ankylosaurians are less than 3 m, such as *Struthiosaurus*, *Minmi*, *Mymoorapelta*, and *Kunbarrasaurus* (Kirkland and Carpenter, 1994; Garcia and Suberbiola, 2003; Leahey et al., 2015). Thus, given the lack of information indicating the precise ontogenetic stage of the specimen, the ankylosaurian specimen from the Longjing Formation (IVPP V26052) at least represents a moderate body-sized ankylosaurian dinosaur.

Ankylosaurian remains are very abundant in China and have been reported from the Jurassic of the Junggar Basin in Xinjiang Uyghur Autonomous Region (Augustin et al., 2020; Dong, 1993); the Lower Cretaceous of Yixian (Xu et al., 2001), the Lower to Upper Cretaceous of Beipiao (Dong, 2002; Lü et al., 2007a; Yang et al., 2017), the Lower Cretaceous of Fuxin (Amiot et al., 2010), the Lower Cretaceous of Lingyuan (Han et al., 2014), and the Lower Cretaceous of Kazuo (Ji et al., 2014) in Liaoning Province; the Lower Cretaceous of Yongjing in Gansu Province (Yang et al., 2013), the Lower Cretaceous of Urad Houqi (Arbour and Currie, 2016; Bohlin, 1953), the Lower and Upper Cretaceous of Alashan (Vickaryous et al., 2001; Young, 1935), and the Upper Cretaceous of Bayan Mandahu (Burns et al., 2011; Godefroit et al., 1999) in Inner Mongolia Autonomous Region; the Upper Cretaceous of Tianzhen (Barrett et al., 1998; Pang and Cheng, 1998), and Zuoyun (Jia, 2018) in Shanxi Province; the Upper Cretaceous of Laiyang in Shandong Province (Buffetaut, 1995); the Cretaceous of Ruyang in Henan Province (Xu et al., 2007); the Cretaceous of Lishui (Lü et al., 2007b), Dongyang (Chen et al., 2013) and Jinyun (Zheng et al., 2018) in Zhejiang Province (Fig. 4). Among them, the localities of Beipiao in Liaoning, Zuoyun in Shanxi, and Lishui, Dongyang, and Jinyun in Zhejiang have similar geological ages to the Longjing Formation (Chen et al., 2013; Yang et al., 2017; Jia, 2018; Zheng et al., 2018). Only two of them are from North China. Wang et al. (2020) reported a new ankylosaur *Sinankylosaurus zhuchengensis* from Upper Cretaceous of Zhucheng, Shandong Province, based on an incomplete right ilium (ZJZ-183). However, this holotype presents no ankylosaur diagnostic features. For instance, the putative acetabulum does not have cup-like structure, nor pubic or ischial peduncle. Moreover, there is no longitudinal preacetabular ridge in the ventral surface anterior to the putative acetabulum (Wang et al., 2020: Fig 2–3). For those reasons, we concluded that ZJZ-183 cannot be referred as an ankylosaur ilium and the diagnosis for ZJZ-183 as a new ankylosaur taxon is invalid. '*Sinankylosaurus zhuchengensis*' is here considered as a nomen dubium, and not an ankylosaur.

The ilium described herein is the first evidence of ankylosaurian dinosaurs from Jilin Province, and is the easternmost known ankylosaurian occurrence in China at present (Fig. 4). Thus, this discovery extends the geographical range of ankylosaurians, and also enriches the middle Cretaceous ankylosaurian record, especially in North China. Unfortunately, the recovered portion prevents further referral of IVPP V26052 to any existing taxa, or to either the subclade of Nodosauridae or Ankylosauridae. The discovery demonstrates the potential of ongoing excavation in the Longjing Formation of Longshan Mountain to recover additional ankylosaurian remains (Zhang et al., 2018).

Fig. 4. Ankylosaurian fossil localities in China. Jurassic and Cretaceous localities are indicated by black squares and red triangles, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

6. Conclusions

The new ankylosaurian ilium (IVPP V26052), from the Albian–Cenomanian Longjing Formation of Yanji City, Jilin Province, northeastern China, represents the first definitive ankylosaurian dinosaur from Jilin Province, and the easternmost ankylosaurian occurrence in China. We estimated the body length of the individual to be around 5–5.5 m. Given the lack of precise ontogenetic stage information of the specimen, it at least represents a moderate body-sized ankylosaurian dinosaur.

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