蒙古戈壁上白垩统的暴龙类额骨

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摘要:记述了发现于蒙古戈壁查干泰格地点的一块额骨。短的眶缘和矢状脊的存在等特征表明,该标本属于暴龙超科。查干泰格地点出露的地层被认为属于森诺曼-桑托期的巴音沙拉组,新材料的发现为上白垩统下部非常稀少的暴龙类恐龙记录增添了新的内容。

关键词:蒙古戈壁;上白垩统;巴音沙拉组;恐龙超目,兽脚亚目,暴龙超科
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A TYRANNOSAUROID FRONTAL FROM THE UPPER CRETACEOUS (CENOMANIAN-SANTONIAN) OF THE GOBI DESERT, MONGOLIA

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Abstract An isolated frontal found at the Tsagaan Teg locality in the Gobi Desert is described. Such features as a short orbital rim and the presence of a sagittal crest indicate that this specimen belongs to Tyrannosauroidea. Because the sediment cropping out at Tsagaan Teg is considered as belonging to the Cenomanian-Santonian Bayn Shire Formation, the present specimen contributes to improving the extremely poor fossil record of tyrannosauroid theropods in the lower Upper Cretaceous.

Key words Gobi Desert, Mongolia; Upper Cretaceous; Bayn Shire Formation; Dinosauria, Theropoda, Tyrannosauroidea

1 Introduction

The fossil record of tyrannosauroid theropods ranges from the Middle Jurassic to the end of the Cretaceous (Rauhut et al., 2009; Brusatte et al., 2010). Before well-known, large-bodied tyrannosaurids appear in the Campanian and Maastrichtian, the tyrannosauroid fossil record is

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extremely poor in the early Late Cretaceous (Cenomanian-Santonian). There have been several reports of tyrannosauroid remains from the latter time interval in North America (e. g., Russell, 1935; Cifelli et al., 1997; Kirkland et al., 1997, 1998; Kirkland and Madsen, 2007; Larson, 2008). Such remains, however, either consisted of isolated teeth or were only briefly mentioned as faunal elements without descriptions or illustrations. In contrast, several studies described tyrannosauroid skeletal remains from putatively coeval deposits in Asia. Whereas fragmentary skeletal remains of this clade of theropods have been described from several Cenomanian-Santonian localities in Central Asia (e. g., Nessov, 1995; Averianov, 2007), better-preserved specimens have been found in the Gobi Desert. First, *Alectrosaurus olseni* was found in the Iren Dabasu Formation of Iren Dabasu in Nei Mongol, China (Gilmore, 1933; Fig. 1). The material of *A. olseni* consists of hind limb and pelvic elements (Mader and Bradley, 1989) and lacks cranial elements. The age of the Iren Dabasu Formation, however, has been debated. Based on vertebrate assemblages, Jerzykiewicz and Russell (1991) correlated the Iren Dabasu Formation with the Bayn Shire Formation in Mongolia, while Currie and Eberth (1993) correlated the former formation specifically with the uppermost levels of the latter. Based on this correlation, Currie and Eberth (1993) considered that the Iren Dabasu Formation is most likely Coniacian or Santonian in age but is possibly as young as Campanian. Godefroit et al. (1998), on the other hand, suggested a Cenomanian age for this formation based on the presence of primitive hadrosaurs. In contrast, Van Itterbeeck et al. (2005) correlated the Iren Dabasu Formation with the Nemegt Formation in Mongolia (Fig. 2) and estimated the age of the former as Campanian-Maastrichtian based on microfossil assemblages. Thus, it is possible that *A. olseni* is not from the early Late Cretaceous but is coeval with the derived tyrannosaurid *Tarbosaurus*

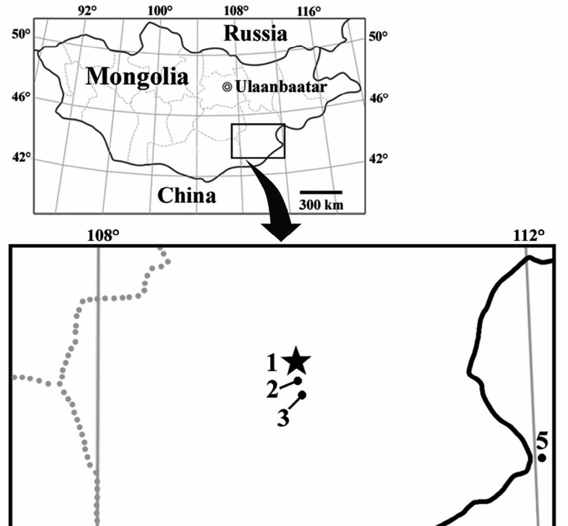

Fig. 1 Map of Mongolia and surrounding regions showing Tsagaan Teg and other lower Upper Cretaceous localities mentioned in the text (partly modified from Tsubamoto et al., 2010)
1. Tsagaan Teg and Khongil Tsav; 2. Burkhant; 3. Bayn Shire; 4. Bayshin Tsav; 5. Iren Dabasu

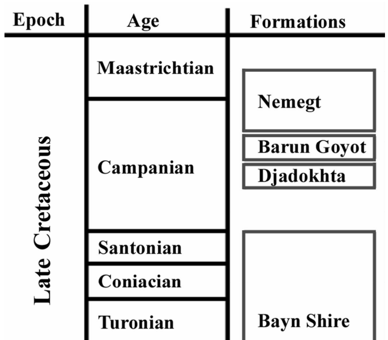

Fig. 2 Chronological relationships of the Upper Cretaceous formations in the Mongolian Gobi Desert
The age estimate for the Bayn Shire Formation follows Hicks et al. (1999) and those for other formations follow Jerzykiewicz (2000)

bataar, which is abundantly found in the Nemegt Formation. The second occurrence of tyrannosauroid material from the early Late Cretaceous of the Gobi Desert was in the Bayn Shire Formation cropping out at Bayshin Tsav in Southern Gobi Aimag of Mongolia (Fig. 1), and was described by Perle (1977). Perle (1977) referred this Mongolian material, which includes both cranial and postcranial elements, to *A. olseni* because the hind limb is similar in its gracile proportions to that of the lectotype of *A. olseni*. This referral, however, is not definite (Mader and Bradley, 1989; Holtz, 2004). In addition, this Mongolian material has been unavailable to outside researchers for years (Currie et al., 2003), preventing adequate redescription. Therefore, anatomical information on the early Late Cretaceous tyrannosauroids is still very sparse.

We here describe a tyrannosauroid frontal found in the Tsagaan Teg region in the eastern Gobi Desert. Although fragmentary, this specimen falls within the stratigraphic range of the early Late Cretaceous, thus improving the currently poor fossil record of tyrannosauroids during this time interval.

Institutional abbreviations MPC, Mongolian Paleontological Center, Ulaanbaatar, Mongolia.

2 Geological setting

The Tsagaan Teg locality is situated about 20 km southwest of Dzun Bayan Somon in the central part of Eastern Gobi Aimag (Fig. 1) and consists of two outcrops, the main outcrop and a second one called Tsagaan Teg West in Watabe et al. (2010) and located about 3 km farther west. The tyrannosauroid frontal described in the present study was found as float on a layer of medium-to-coarse-grained sandstone at Tsagaan Teg West during the 2008 field season of the Hayashibara Museum of Natural Sciences-Mongolian Paleontological Center Joint Paleontological Expedition (Tsubamoto et al., 2010). The sediments cropping out at Tsagaan Teg consist of alternating beds of sandstone and mudstone. Based on the evolutionary grade of the ankylosaur *Tsagantegia longicranialis* found in this locality, Tumanova (1993) inferred that the Tsagaan Teg sediments belonged to the Bayn Shire Formation. Watabe et al. (2010) also correlated the sediments of this locality with the Bayn Shire Formation cropping out at the Khongil Tsav locality (Jerzykiewicz and Russell, 1991) situated 3.3 km northeast of the main outcrop of Tsagaan Teg. The age of the Bayn Shire Formation has been inferred based mainly on vertebrate and invertebrate fossils (e.g., Martinson, 1982; Jerzykiewicz and Russell, 1991; Jerzykiewicz, 2000). Hicks et al. (1999) conducted paleomagnetic analysis on sediments of the Bayn Shire Formation cropping out at the Bayn Shire and Burkhant localities (Fig. 1) and found that these sediments correlate to the Cretaceous Long Normal interval of the Geomagnetic Polarity Time Scale. Based on this result combined with previous biostratigraphic age estimates, Hicks et al. (1999) inferred the age of this formation to be Cenomanian-Santonian (Fig. 2).

3 Description of the specimen

The present specimen, MPC-D 102/4, is an isolated, mostly complete left frontal lacking only the anterior part of the sagittal crest and part of the postorbital sutural area that are broken off and missing (Figs. 3, 4). The overall shape is that of an anteroposteriorly-elongated triangle. The width-to-length ratio (ratio of the width measured at the orbital rim to the maximum

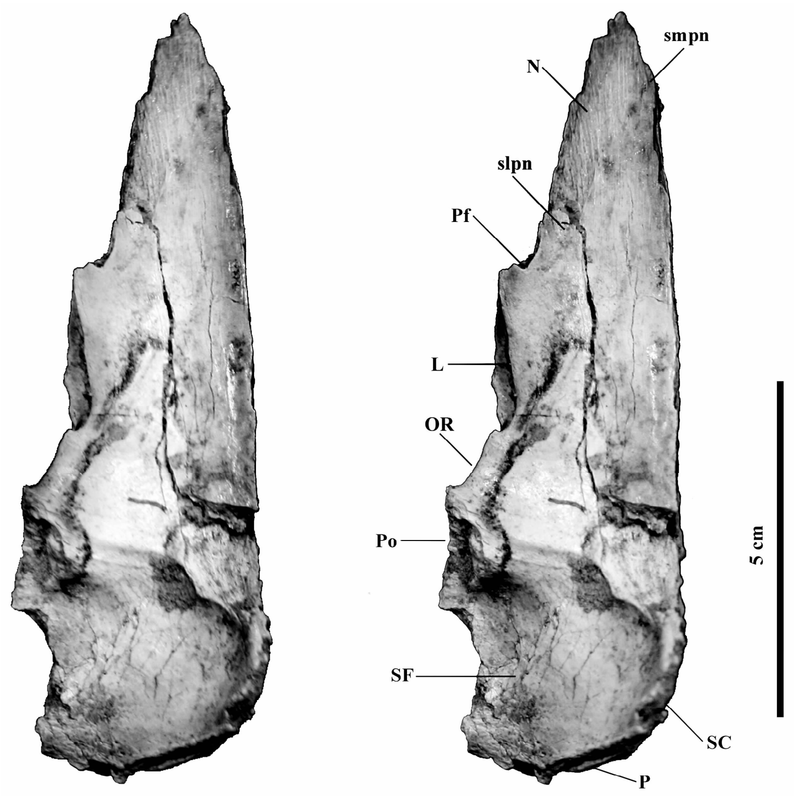

Fig. 3 Stereopair of MPC-D 102/4 in dorsal view
Abbreviations: L. groove for articulation with the lacrimal; N. sutural surface for the nasal; OR. orbital rim; P. sutural surface for the parietal; Pf. anterior end of the groove for articulation with the prefrontal; Po. sutural surface for the postorbital; SC. sagittal crest; SF. supratemporal fossa; slpn and smpn. slots for the lateral and medial prongs of the nasal, respectively

anteroposterior length) is 0.27 (Fig. 4). For comparison, the same ratio is 0.40 in a specimen of *Tarbosaurus bataar* (MPC-D 107/14) in which the length of the frontal is 145 mm. This demonstrates rather slender, elongated proportions of MPC-D 102/4. It is noteworthy that the width-to-length ratio increases ontogenetically in tyrannosaurids along with cranial fusion (Carr, 1999; Currie, 2003). It is possible, therefore, that the small ratio found in MPC-D 102/4 reflects immaturity of the specimen.

The dorsal surface of the bone is nearly flat anterior to a buttress of the postorbital suture surface. This buttress marks the anterior margin of the supratemporal fossa, which is medially bounded by a well-developed sagittal crest continued from the parietal (Figs. 3, 4, 5, 7A). The dorsal surface of the frontal portion of the supratemporal fenestra is shallowly depressed and bears a scar.

The anterior part of the bone bears a well-developed sutural surface for the nasal on the dorsal surface (Figs. 3, 4). This sutural surface appears to include a very small slot along the medial margin of the bone for articulation with a tiny, medial prong of the nasal, in addition to a much larger slot laterally for the lateral prong of the nasal (Fig. 3). In dorsal view, there is a notch adjacent and posterolateral to the area for articulation with the lateral prong of the nasal.

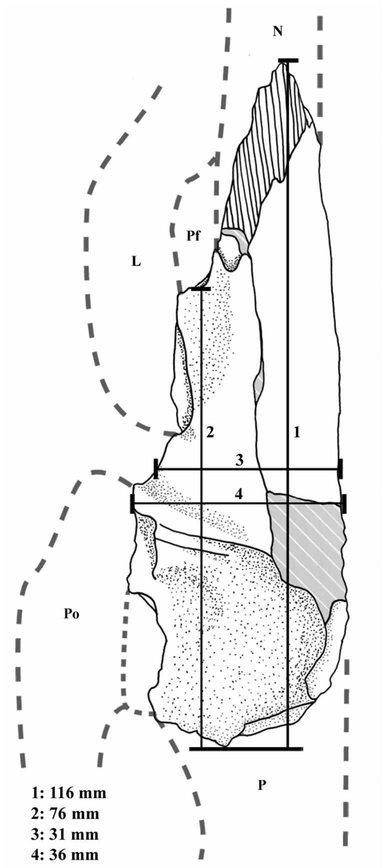

Fig. 4 Illustration of MPC-D 102/4 in dorsal view with several measurements (1-4)
Cranial bones surrounding the frontal are reconstructed to show their positional relationships
Measurements: 1. maximum anteroposterior length; 2. anteroposterior length between the prefrontal and parietal sutures; 3. width at the orbital rim; 4. maximum width
Abbreviations: L. lacrimal; N. nasal; P. parietal; Pf. prefrontal; Po. postorbital

This notch represents the anterior end of a deep groove for articulation with the prefrontal (Figs. 3, 4, 5, 6). This groove continues along the lateral aspect of the frontal, extending posteriorly and slightly ventrally. At its posterior end, this groove curves ventrally onto the anterolateral edge of the crista cranii, producing a vertical contact between the frontal and prefrontal (Fig. 5). Dorsal to this groove lies another groove for articulation with the lacrimal, extending anteroposteriorly (Figs. 3, 4, 5). This configuration suggests that the posterior part of the lacrimal articulates directly with the frontal on the dorsal surface (Fig. 4).

Posterior to the lacrimal articulation groove lies the orbital rim, which is anteroposteriorly abbreviated (Figs. 3, 4). Only the anterior part of the sutural surface for the postorbital is preserved (Figs. 3, 4), and this preserved part is dorsoventrally high in lateral view (Fig. 5). A well-developed buttress extends medially from this sutural surface for the postorbital on the dorsal aspect of the bone. The sutural surface for the parietal is inclined dorsomedially toward the sagittal crest in posterior view (Fig. 7B). In dorsal view, this sutural contact is almost a straight, transverse line except near the midline, where the parietal wedges anteriorly to overlap the frontal (Figs. 3, 4). Near the lateral end of the parietal suture, the sutural surface for the laterosphenoid extends ventrally on the posterior edge of the crista cranii (Figs. 5, 7B). The medial, interfrontal suture is a straight line in dorsal view, lacking interdigitation.

In ventral view, a ventrally-extending crista cranii demarcates the endocranial cavity and constricts it medially (Fig. 6). Anterior and posterior to this constriction are the dorsal roofs of the olfactory bulb and anterior portion of the cerebrum, respectively, and the olfactory tract connecting these two structures would have extended though the constriction (e. g., Ali et al., 2008). Anterior to the crista cranii, a longitudinal ridge extends anteroposteriorly. Medial to this ridge is an area covered by longitudinal striations (Fig. 6). This area may in part represent the attachment for the possibly cartilaginous dorsal plate and median septum of the "ethmoid complex" or mesethmoid *sensu* Ali et al. (2008)

4 Discussion

MPC-D 102/4 possesses many features that were considered diagnostic of Late Cretaceous tyrannosaurids by Currie (1987). Such features include a short orbital rim (characteristic present in various tyrannosaurids as well as in *Xiongguanlong* [Brusatte et al., 2010]), an expanded suture between the frontal and postorbital that is buttressed at its anterior end, the sagittal crest extending onto the frontal, a flat dorsal surface of the bone between the orbits, and the supratemporal fossa extensively covering the dorsal surface of the bone. These features, therefore, indicate that MPC-D 102/4 likely belongs to a tyrannosaurid or possibly a close relative of tyrannosaurids.

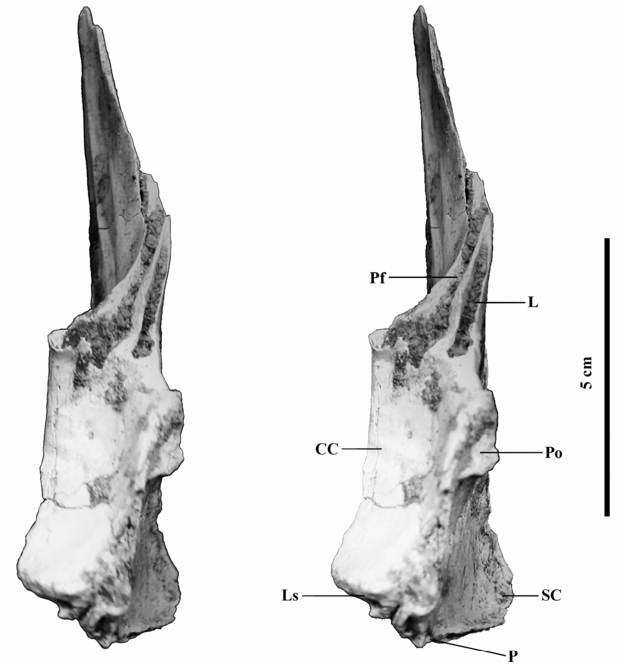

Fig. 5 Stereopair of MPC-D 102/4 in left lateral view
Abbreviations: CC. crista cranii; L. groove for articulation with the lacrimal; Ls. sutural surface for the laterosphenoid; P. sutural surface for the parietal; Pf. groove for articulation with the prefrontal; Po. sutural surface for the postorbital; SC. sagittal crest

In order to infer the phylogenetic position of MPC-D 102/4, we analyzed it using Brusatte et al.'s (2010) tyrannosauroid data matrix by scoring eight frontal characters (see Appendix for coding of MPC-D 102/4) and running an analysis using TNT version 1.1 (Goloboff et al., 2008) under the "Implicit enumeration" option. This analysis resulted in nine most parsimonious trees, which have a tree length of 557, consistency index of 0.64, and retention index of 0.84. The strict consensus of these nine trees (Fig. 8) shows that MPC-D 102/4 falls within a large polytomy encompassing taxa more derived than Proceratosauridae and *Dilong*. This polytomy was caused by MPC-D 102/4 acting as a 'wildcard' taxon, as a result of high amounts of missing data and/or character conflict. That is, except for unstable positions of MPC-D 102/4, all nine most parsimonious trees have the same branching pattern for the non-proceratosaurid part of the tree, which is identical to that of the single most parsimonious tree obtained in Brusatte et al.'s (2010) original analysis. The present analysis, however, does suggest that MPC-D 102/4 belongs to a taxon more derived than Proceratosauridae and *Dilong*. Such a phylogenetic position of MPC-D 102/4 is supported by derived morphology of the supratemporal fossa, i. e., the anteroposterior length of the supratemporal fossa being more than 30% of the length of the exposed part of the frontal on the skull roof (state 1 of character 115) and contralateral supratemporal fossae meeting at the midline (state 1 of character 116), both observed in the specimen.

Because MPC-D 102/4 is fragmentary, a more expansive phylogenetic assessment is not possible. Nor is it possible to directly compare it with coeval tyrannosauroid material referred to *Alectrosaurus olseni* by Perle (1977), because the latter does not include a frontal. However, the present discovery confirms the potential of the Bayn Shire Formation in general, and the Tsagaan Teg locality in particular, as a new source of information on the diversity of Tyrannosauroidea during the early Late Cretaceous, from which very little material of this clade of theropods has been reported. With further paleontological work, this region of Mongolia will offer a rare window into an enigmatic time interval of tyrannosauroid evolution.

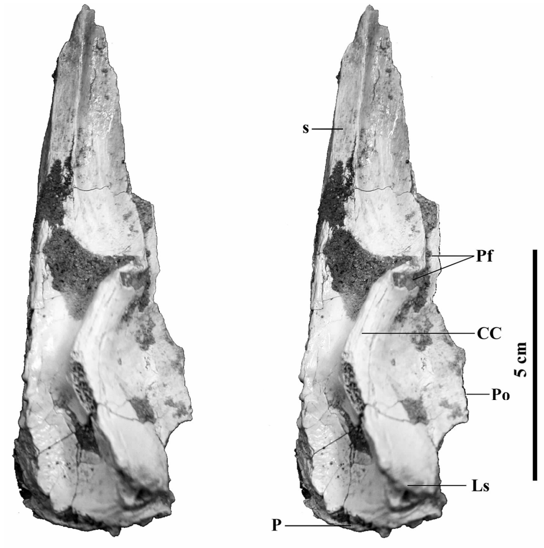

Fig. 6 Stereopair of MPC-D 102/4 in ventral view
For abbreviations see Fig. 5 plus s. striated surface

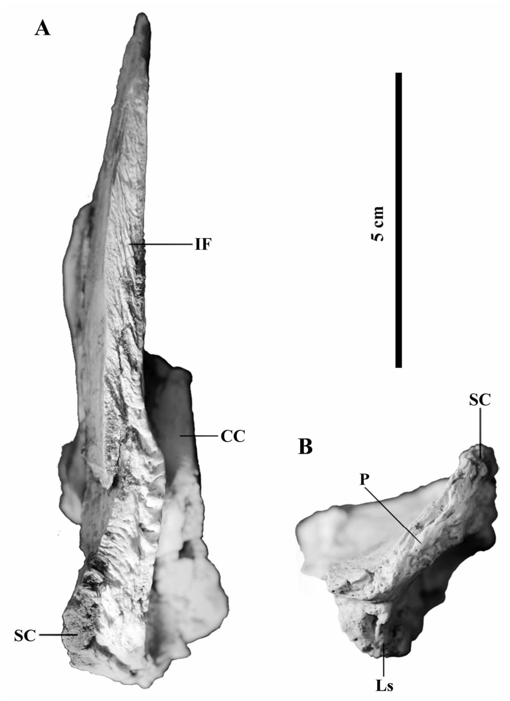

Fig. 7 MPC-D 102/4 in medial (A) and posterior (B) views
For abbreviations see Fig. 5 plus IF. interfrontal sutural surface

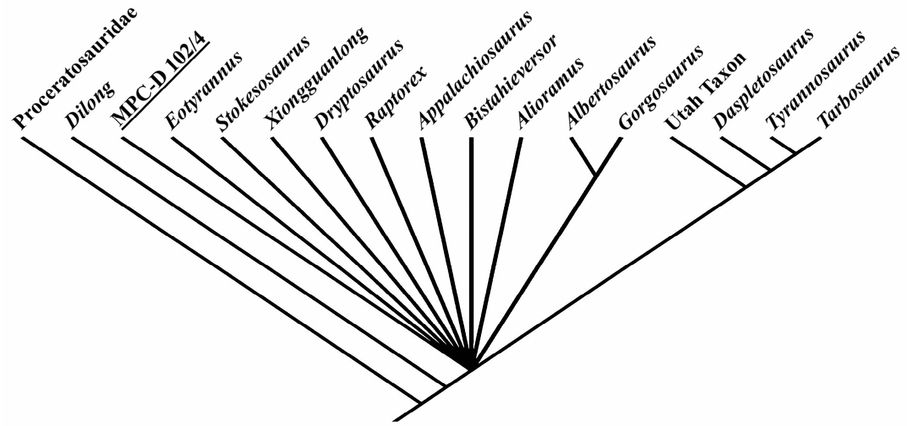

Fig. 8 Strict consensus of nine most parsimonious trees resulting from the phylogenetic analysis of Tyrannosauroidea based on the data matrix of Brusatte et al. (2010) with MPC-D 102/4 added

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Appendix Character state values of MPC-D 102/4 for characters 113 through 120 in the data matrix by Brusatte et al. (2010), newly coded in the present phylogenetic analysis

Characters	113	114	115	116	117	118	119	120
State	0	0	1	1	1	0	2	1