A New Troodontid (Theropoda: Troodontidae) from the Lower Cretaceous Yixian Formation of Western Liaoning, China

XU Xing and WANG Xiaolin
Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Beijing, 100044; *E-mail*: *xu.xing@pa.ivpp.ac.cn*

Abstract A specimen collected from the Lower Cretaceous Yixian Formation of western Liaoning, China, represents a new genus and species of troodontid theropod. The new taxon is named and described on the basis of the holotype and the only known specimen, which comprises an articulated skeleton with the presacral vertebral, shoulder girdle and forelimbs missing as preserved. Diagnostic features of the new species include nasals that are sinusoid in lateral view, absence of a passage connecting the antorbital and maxillary fenestrae, relatively large teeth, plate-like chevrons forming a band along most of the length of the tail, and a long neck between the femoral head and shaft. The temporal constraints of the three paravian groups (Troodontidae, Dromaeosauridae and Aves) combined with the character distributions among the earliest known troodontids indicate a rapid evolution at the base of the Troodontidae.

Key words: Early Cretaceous, Yixian Formation, Troodontidae, western Liaoning, China

1 Introduction

Troodontids represent one of the most bird-like theropod groups (Currie, 1985, 1987; Forster et al., 1998; Currie and Dong, 2001; Xu et al., 2002c) and, together with dromaeosaurids, have been regarded by many authors to be the closest relatives of birds (Gauthier, 1986; Makovicky and Sues, 1998; Sereno, 1999; Xu et al., 2002c). Troodontidae are known only from Cretaceous deposits of northern continents (Osborn, 1924; Barsbold, 1974; Russell and Dong, 1993; Norell et al., 2000; Xu et al., 2002c). The earliest known taxon that can be confidently referred to this group is *Sinovenator changii*, which was recovered from the lowest part of the Yixian Formation at the Lujiatun locality of western Liaoning, China (Xu et al., 2002c), a locality that has recently produced several important dinosaur taxa (Xu et al., 2000, 2002a, b, c; You et al., 2003). Recent studies on some troodontid specimens collected from this and nearby localities have led to the identification of a second new troodontid species other than *Sinovenator changii*. Here we report the new discovery and its implication for understanding the early evolution of the troodonttnids.

2 Systematic Paleontology

Theropoda Marsh, 1884
Coelurosauria Huene, 1914
Troodontidae Gilmore, 1924
Sinusonasus magnodens gen. et sp. nov.

Holotype: IVPP (Institute of Vertebrate Paleontology and Paleoanthropology, Beijing) V11527, an articulated skeleton missing the presacral vertebraes, shoulder girdles and forelimbs (Figs. 1, 2).

Etymology: The generic name refers to the sinusoid nasal; the specific name refers to the relatively large dentition.

Type Locality and horizon: Lujiatun locality, Beipiao, Liaoning Province, China; Yixian Formation, Hauterivian Early Cretaceous (Swisher et al., 2001).

Diagnosis: A small-sized troodontid differs from other troodontids in apomorphically having a sinusoid nasal in lateral view, absence of a passage connecting antorbital and maxillary fenestrae, relatively large teeth; plate-like chevrons forming a band-like structure along the most length of the tail, and a long neck between the femoral head and shaft.

Description: The holotype is an adult animal as indicated by the complete fusion of the neural arch with the centrum on all visible vertebrae. With a femur about 141 mm long, *S. magnodens* is larger in size than *Sinovenator changii.*

The skull is proportionately small, with a skull/femur length ratio of about 0.77, as in some basal dromaeosaurids and troodontids (Xu, 2002). In lateral view, the snout has a sinusoid dorsal margin because of the modified nasals. The body of the premaxilla is deep dorsoventrally as in some derived troodontids (Osmólska and Barsbold, 1990). In lateral view, the maxilla contributes to the formation of the

Fig. 1. Photograph of the holotype of *Sinusonasus magnodens* gen. et sp. nov. (IVPP V11527).
Scale bar equals 1 cm.

ventral border of the external naris; close examination reveals, however, that a slender subnarial process of the premaxilla contacts the nasal below the external naris. The antorbital fossa, with a relatively rounded ventral rim, contains a relatively small antorbital fenestra, a large maxillary fenestra and a slit-like promaxillary fenestra. In *S. changii*, the promaxillary fenestra is represented by a distinctive opening (Xu et al., 2002c). The nasal is depressed above the external naris as in some velociraptorines (Barsbold and Osmólska, 1999; Xu, 2002) and is again depressed above the maxillary fenestra, thus making a sinusoid outline in lateral view. As in *S. changii* (Xu et al., 2002c), the lateral edge of the nasal forms a small shelf adjacent to the nasomaxillary suture. The lacrimal is T-shaped in lateral view, with a relatively long rostral process and a pronounced lateral projection that overhangs the descending process. A pneumatic fossa, present in other troodontids and many coelurosaurs (Currie and Dong, 2001), appears to be absent at the junction of the rostral and descending processes. As in other troodontids, a row of foramina is located in a groove posteriorly on the sub-triangular labial surface of the dentary (Norell et al., 2000), though the groove is relatively shallower. In lateral view, the ventral margin of the dentary is considerably convex.

There are about 19 maxillary teeth, less than in *S. changii* (Xu et al., 2002c). Both maxillary and dentary teeth show troodontid dental feature in that they are small and closely packed anteriorly, and larger and more sparsely distributed posteriorly, as in other troodontids (Currie, 1987). The middle maxillary teeth are significantly larger than the teeth anterior and posterior to them, and are comparatively larger in size than those of other troodontids. Denticles are absent on anterior teeth, and are present only on posterior carinae of posterior teeth. They appear to be relatively small and

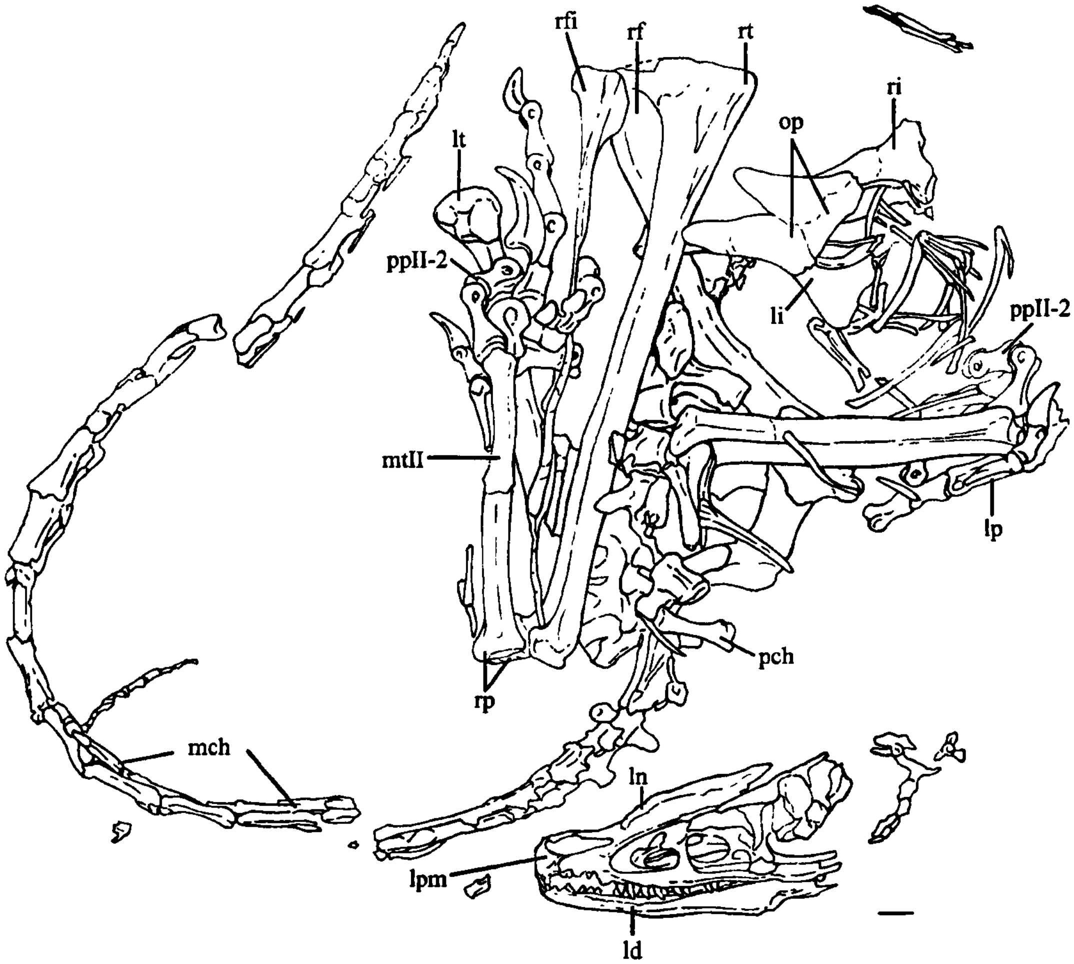

Fig. 2. Line drawing of the holotype of *Sinusonasus magnodens* gen. et sp. nov. (IVPP V11527).
Scale bar equals 1 cm.
Abbreviations: li – left ischium; lpm – left premaxilla; ld – left dentary; ln – left nasal; lp – left pes; lt – left tibia; mch – chevron on middle caudals; mtII – metatarsal II; pch – chevrton on proximal caudals; ppII-2 – pedal phalanx II-2; op – obturator process; rf – right femur; rfi– right fibula; ri – right ischium; rp – right pes; rt – right tibia.

lack a hooked tip.

Five sacrals make ups the sacrum and all are similar in size, unlike the condition in *S. changii*, basal dromaeosaurids and birds, in which the middle ones sacrals are significantly enlarged (Xu et al., 2002c). About 30 caudals are visible on the holotype and the middle and distal caudals are elongated, about 1.9 times as long as the anteriormost caudals. The distal caudals display a few troodontid features such as the presence of a sulcus on the dorsal surface (Russell and Dong, 1993) and centrum significantly smaller than the corresponding neural arch. The middle and distal chevrons are plate-like and contact each other to form a ventral band below the caudal centra.

The pubis is probably anteriorly oriented as indicated by the steeply inclined iliac articular surface, the anteroposteriorly long ischiadicl peduncle, and the slightly anterior curvature of the shaft. The ischium is almost identical to that of more derived troodontids such as *Saurornithoides mongoliensis* (Russell, 1969). It is relatively long (about 54% the length of the pubis, compared to about 40% in *Sinovenator changii*), and has a smooth, strongly concave posterior margin and a large triangular obturator process positioned at the mid-shaft.

The femur is unusual in having a long neck between the femoral head and shaft. Like some derived troodontids (Osmólska and Barsbold, 1990; Currie and Peng, 1993), the greater and lesser trochanter fused together to form a trochanteric shelf at the same level with the femoral head.

As in other troodontids, the tibioatarsus and pes are subequal to each other in length and they are elongated, about 132% length of the femur. The metatarsus is in the typical arctometatarsalian condition in which the proximal end of metatarsal III is strongly pinched and not visible anteriorly. Also as in other troodontids, metatarsal II is short and slender and metatarsal IV is robust. Like derived troodontids and dromaeosaurids, pedal digit II is highly specialized in having an abbreviated second phalanx with a prominent proximoventral heel and an enlarged ungual. Comparatively, *Sinovenator changii* and some basal dromaeosaurids have a less abbreviated second phalanx with a weak proximoventral heel and a relatively small ungual (Xu and Wang, 2000).

3 Discussion

The troodontid status of *S. magnodens* is indicated by the following derived features: numerous tightly packed anterior teeth, roughly triangular dentary in lateral view with mental foramina in a groove (Currie, 1987), a T-shaped lacrimal with a long anterior process, distal caudals with sagittal sulcus above neural canal and significantly reduced centrum, and metatarsal II slender and shorter than metatarsal IV (Currie and Peng, 1993; Norell et al., 2000).

Among the known troodontids, *S. magnodens* is probably more derived than *S. changii* and *Sinornithoides youngi*. It shares a number of features with later, more derived troodontids that are absent in *S. changii*, such as an anteroventrally oriented pubis, the large triangular obturator process positioned at the mid-shaft of the ischium, absence of a posterodorsal and a posteroventral process of the ischium, the presence of fully arctometatarsalian metatarsus, and pedal phalanx II-2 highly abbreviated and with developed proximoventral heel. It also seems to be more derived than *Sinornithoides youngi* based on some features on the ischium and caudals (Russell and Dong, 1993; Currie and Dong, 2001). For example, the ischium of *Sinornithoides youngi* displays an intermediate condition between *Sinovenator changii* and more derived troodontids, including *S. magnodens*, in having a smaller and more distally positioned obturator process, and the distal caudals lack a dorsal sulcus which is present in *S. magnodens* and other troodontids. Although small size, unserrated anterior teeth and relatively small-sized denticles on the middle and posterior teeth suggest that *S. magnodens* might be more primitive than most Late Cretaceous troodontids, a precise phylogenetic position of *S. magnodens* has to be determined by a numerical cladistic analysis, which is, however, beyond the scope of the present paper.

The coexistence of *S. magnodens*, a relatively derived troodontid, and *S. changii*, the most basal known troodontid known to date, during the Hauterivian time in western Liaoning has bearing on understanding the early evolution of troodontids. Among the three paravian lineages (Aves, Dromaeosauridae, and Troodontidae), the earliest known avian is from the Tithonian Late Jurassic and the oldest troodontids and dromaeosaurids are from the Hauterivian Early Cretaceous. Given that 1) *S. changii* is extremely similar to the basal dromaeosaurid *Microraptor* (Hwang et al., 2002; Xu, 2002), 2) both *S. changii* and *S. magnodens* possess most troodontid diagnostic features, and 3) the latter possesses a number of reversal features absent in *S. changii* but present in later, highly derived troodontids, it is inferred that 1) the basal deinonychosaur split might not be significantly earlier than Hauterivian, possibly in the earliest Cretaceous; and 2) the troodontids have rapidly acquired most of their autopomorphies and derived troodontid lineage have reversed to more primitive condition in many characters rapidly after the origin of troodontids. Although previous studies often predicted an older fossil record for the troodontids and other derived coelurosaurian lineages (Sereno, 1999; Xu et al., 2001), the combination of the termporal constraints of the three paravian lineages with the character distribution among the earliest known troodontids and basal dromaeosaurids indicates that the troodontids might be restricted to the Cretaceous time and they probably have a rapid rate of character evolution at the base of the group.

Acknowledgments

We thank James Clark for editing the manuscript, Cao Renfang and Wang Haijun for preparing the specimen, Zhou Zhonghe, Li Yan, Wang Haijun, Huo Yülong, Shou Huaquan, Liu Xinzhen, Cao Qiang, Chen Wei, Lü Junchang, and Li Chun, among others, for their contribution in the field, the National Natural Science Foundation of China, National Geographic Society, Special Funds for Major State Basic Research Projects of China, and Chinese Academy of Sciences for financial support.

Manuscript received Dec. 24, 2003
accepted Jan. 14, 2004
edited by Xie Guanglian

References

Barsbold, R., and Osmólska, H., 1999. The skull of *Velociraptor* (Theropoda) from the late Cretaceous of Mongolia. *Acta Palaeontologica Polonica*, 44(2): 189–219.

Barsbold, R., 1974. Sauromithoididae, a new family of small theropod dinosaurs from Central Asia and North America. *Palaeontologia Polonica*, 30: 5–22.

Currie, P.J., and Dong Zhiming, 2001. New information on Cretaceous troodontids (Dinosauria, Theropoda) from the

People's Republic of China. *Canadian Journal of Earth Sciences*, 38: 1753–1766.

Currie, P.J., and Peng, J.H., 1993. A juvenile specimen of *Saurornithoides mongoliensis* from the Upper Cretaceous of northern China. *Canadian Journal of Earth Sciences*, 30: 2224–2230.

Currie, P.J., 1985. Cranial anatomy of *Stenonychosaurus inequalis* (Saurischia, Theropoda) and its bearing on the origin of birds. *Canadian Journal of Earth Sciences*, 22: 1643–1658.

Currie, P.J., 1987. Bird-like characteristics of the jaws and teeth of troodontid theropods (Dinosauria: Saurischia). *Journal of Vertebrate Paleontology*, **7**: 72–81.

Forster, C.A., Sampson, S.D., Chiappe, L.M., and Krause, D.W., 1998. The theropod ancestry of birds: new evidence from the Late Cretaceous of Madagascar. *Science*, 279: 1915–1919.

Gauthier, J., 1986. Saurischian monophyly and the origin of birds. *Memoirs of the California Academy of Sciences*, 8: 1–55.

Hwang, S., Norell, M.A., Ji, Q., and Gao, K.Q., 2002. New specimens of *Microraptor zhaoianus* (Theropoda, Dromaeosauridae) from northeastern China. *American Museum Novitates*, 3381: 1–44.

Makovicky, P., and Sues, H.-D., 1998. Anatomy and phylogenetic relationships of the theropod dinosaur *Microvenator celer* from the Lower Cretaceous of Montana. *American Museum Novitates*, 3240: 1–27.

Norell, M.A., Makovicky, P., and Clark, J.M., 2000. A new troodontid theropod from Ukhaa Tolgod, Mongolia. *Journal of Vertebrate Paleontology* 20(1): 7–11.

Osborn, H.F., 1924. Three new Theropoda, *Protoceratops* zone, central Mongolia. *American Museum Novitates*, 144: 1–12.

Osmólska, H., and Barsbold, R., 1990. Troodontidae. In: Weishampel, D.B., Dodson, P. and Osmólska, H. (eds.), *The Dinosauria.* Berkeley: University of California Press, 259–268.

Sereno, P.C., 1999. The evolution of dinosaurs. *Science*, 284: 2137–2147.

Russell, D.A., 1969. A new specimen of *Stenonychosaurus* from the Oldman Formation (Cretaceous) of Alberta. *Canadian Journal of Earth Sciences*, 6: 595–612.

Russell, D.A., and Dong Zhiming, 1993. A nearly complete skeleton of a new troodontid dinosaur from the Early Cretaceous of the Ordos Basin, Inner Mongolia, People's Republic of China. *Canadian Journal of Earth Sciences*, 30: 2163–2173.

Swisher, C.C., Wang Xiaolin, Zhou Zhonghe, Wang Yuanqing, Jin Fan, Zhang Jiangyong, Xu Xing, Zhang Fucheng and Wang Yuan, 2001. Further support for a Cretaceous age for the Feathered-Dinosaur Beds of Liaoning, China: New $^{40}Ar/^{39}Ar$ Dating of the Yixian and Tuchengzi Formations. *Chinese Science Bulltin*, 46(23): 2009–2013.

Xu Xing, Wang Xiaolin and You Hailu, 2000. A primitive ornithopod from the Early Cretaceous Yixian Formation of Liaoning. *Vertebrata PalAsiatica*, 38(4): 318–325.

Xu, X., 2002. Deinonychosaurian Fossils from the Jehol Group of Western Liaoning and the Coelurosaurian Evolution. Ph.D. dissertation, Chinese Academy of Sciences, 322.

Xu, X., Cheng, Y.-N, Wang, X.-L., and Chang, C.H., 2002a. An unusual oviraptorosaurian dinosaur China. *Nature*, 419: 291–293.

Xu, X., Makovicky, P., Wang, X.-L, Norell, M.A., and Hai, L.-Y., 2002b. A new ceratopsian dinosaur from China: implications for the early evolution of Ceratopsia. *Nature*, 416: 314–317

Xu, X., Norell, M.A., Wang, X-L, Makovicky, P.J., and Wu, X-C., 2002c. A basal troodontid from the Early Cretaceous of China. *Nature*, 415: 780–784.

Xu, X., and Wang, X.-L., 2000. Troodontid-like pes in the dromaeosaurid *Sinornithosaurus*. *Paleontology Society of Korea, Special Publication*, 2000(4): 179–188.

Xu, X., Zhao, X.J., and Clark, J., 2001. A new therizinosaur from the Lower Jurassic Lufeng Formation of Yunnan, China. *Journal of Vertebrate Paleontology*, 21: 477–483.

You Hailu, Xu Xing and Wang Xiaolin, 2003. A new genus of Psittacosauridae (Dinosauria: Ornithopoda) and the origin and early evolution of marginocephalian dinosaurs. *Acta Geologica Sinica* (English edition), 77(1): 15–20.