

# PHYLOGENETIC ASSESSMENT OF A MANIRAPTORAN FROM THE MORRISON FORMATION

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## Abstract

WDC DML001 was collected in east-central Wyoming in 2000. The delicate nature of the bones required extremely meticulous preparation, as well as computed tomography scanning, before description was possible. The associated skeleton represents approximately 60% of an individual, including significant portions of the skull, axial column, and appendicular skeleton. Total length is estimated to be less than 1.5 meters. WDC DML001 has a pneumatic quadrate, well-developed semilunate carpal, and an elongate forelimb and manus. The specimen exhibits numerous troodontid synapomorphies, including nutrient foramina that lie within a deep groove on the external surface of the dentary and an antorbital fossa with distinct rim. Fusion of the neural arches suggest the animal was at or near adult size. Other phylogenetically important characters include slightly constricted tooth roots, a T-shaped lacrimal, extreme reduction of the fibula, and the presence of an arctometatarsalian pes.

WDC DML001 is the most complete maniraptoran yet described from the Morrison. Phylogenetic analysis strongly supports inclusion of this Jurassic specimen within the Troodontidae. As such, it unambiguously establishes that non-avian maniraptorans date back to the age of the oldest described fossil birds.

The presence of troodontids in North America and archaeopterygians in Europe during the Late Jurassic suggests that maniraptorans were already widespread through the northern hemisphere by this time. Limb proportions and pedal morphology of the specimen are strongly suggestive of a terrestrial lifestyle. The age of WDC DML001 supports the close phylogenetic relationship between birds and deinonychosaurs, while its functional morphology is consistent with a terrestrial origin of flight.

## Introduction

In the summer of 2001, a Tate Museum field crew lead by William Wahl discovered a small (estimated length: 1m) theropod skeleton. The skeleton was found in the Morrison Formation near Douglas, Wyoming, overlying the excavation site of a *Supersaurus vivianae* (Lovellace, 2004). Preparation of the specimen (WDC DML001) has been slow, owing to the delicate nature of the small bones. In 2004 supplementary data was obtained from a CT scan overseen by UT Austin technicians. The data was later processed in Amira to produce 3D images useful for morphological evaluation. Continued preparation and analysis of the CT scan data have allowed a robust evaluation of the phylogenetic status of WDC DML001.

## Ontogeny

The small size of WDC DML001 raises the question of whether the individual had reached maturity. The specimen appears to be at or near adult size based on the following observations: 1) all preserved neural arches appear fused to their respective centra. 2) all preserved long bones have well formed articular ends, and there is no evidence of growth plates. 3) some of the cervical ribs are fused. In addition, some characters (e.g. elongate hard palate, anteriorly forked chevrons) are incompatible with the specimen being the juvenile of known adult theropod taxa from the Morrison Formation. In light of this, and the absence of any obvious juvenile characters (e.g. large skull), the most plausible interpretation is that WDC DML001 is at or near full size.

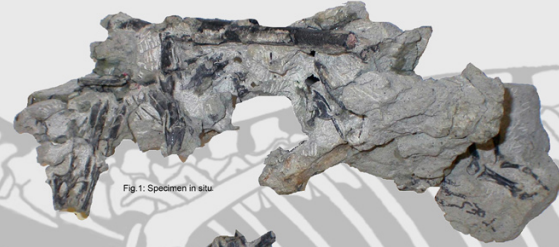


Fig. 1: Specimen in situ.

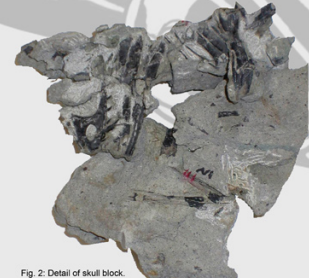


Fig. 2: Detail of skull block.



Fig. 3: CT scan of dentaries. Note nutrient foramina laying within groove on lateral surface.

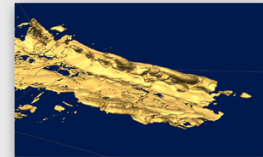


Fig. 4: CT scan of palate. Anterior is to the right.

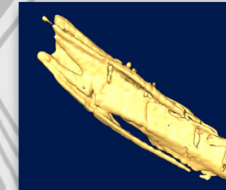


Fig. 5: Dorsal view of distal caudal vertebra. Anterior is towards lower left corner.



Fig. 6: Labial view of left maxillary tooth.



Fig. 8: Rigorous skeletal reconstruction of WDC-DML001.



Fig. 9: Strict consensus cladogram, using matrix from Xu & Norell (2004).



Fig. 10: Topology of Troodontidae found when Mei is excluded from analysis.



Fig. 11: Cervical vertebra, anterior is to the right.



Fig. 12: Isolated ungual, possibly from pedal digit II.

## Taphonomy

WDC DML001 was excavated ~50 meters above the upper contact with the Sundance Formation, and 20 meters below the basal contact of the Cloverly Formation. The specimen was found in a well-demarcated horizon ~5 cm above a bone bearing layer that has been described as a debris flow (Lovellace, 2004). The contact is characterized by a transition from poorly developed soils with distinct abundant mottles to poorly sorted very fine-grained sandstone with a randomly oriented illite matrix. The sandy-clay unit grades upward into a mixed smectite/illite clay layer containing charophytes, conchostraca, and rapidly decreasing sand content. The transitional zone is ~50 cm in thickness and is interpreted as an onlapping lacustrine sequence. The long bones and pneumatic spaces in the vertebrae have been infilled with barite (BaSO<sub>4</sub>).

WDC DML001 was found in the sandy-clay near the contact with the horizon below. The skeleton is tightly associated (under 0.5 square meters), and the bones lack abrasion and other indications of transport. Given its low energy depositional environment, partial articulation, and lack of adjacent fossil bone, there is little doubt that WDC DML001 represents a single individual.



Fig. 7: Cross-section of left metatarsal packet showing arctometatarsalian condition.

## Phylogenetic Analysis

An in-depth description of WDC DML001 is in prep, but it can be diagnosed as a troodontid by the following synapomorphies: antorbital fossa with distinct anteroventral rim; nutrient foramina lay within a deep groove on lateral surface of the dentary; lacrimal anterior dorsal process much longer than the posterior process; pes asymmetrical, with slender MTII and robust MT IV; and distal caudal neural spines have a midline sulcus in center of neural arch.

WDC DML001 shares with other paravians anteriorly bifid distal caudal chevrons. It shares with other maniraptorans: short broad cervical ribs subequal or shorter to cervical centra length, and an absence of distinct interdigital plates in the dentary.

We added WDC DML001 to various published matrices relevant to troodontid systematics, including Xu et al. (2002), and Xu and Norell (2004). WDC DML001 consistently falls within the Troodontidae. Fig. 9 shows a strict consensus tree of findings using the Xu and Norell (2004) matrix. Fig. 10 shows a detail of relationships within the Troodontidae when Mei is removed. Notice that the addition of new Asian taxa cause WDC DML001 to move from a basal position within the Troodontidae to being a more derived troodontid (see discussion below). Regardless of intraclade position, all available data matrices reproduce a troodontid affinity for WDC DML001.

## Discussion

WDC DML001 is the first non-bird paravian from the Jurassic represented by skeletal remains. Morphological differences between the teeth of WDC DML001 and other Jurassic "troodontid" taxa (e.g. *Richardoestesia*) known only from teeth cast doubt on their phylogenetic status.

Originating from the Late Jurassic Morrison Formation, WDC DML001 is roughly contemporary with the Late Jurassic Solnhofen deposits containing *Archaeopteryx*. Therefore WDC DML001 erases the last vestiges of a "time paradox" between birds and their deinonychosaur relatives.

While removing the "infamous" Early Cretaceous ghost lineage for deinonychosaurs, the geographic location of WDC DML001 demonstrates that by the Late Jurassic paravians had already radiated across Europe and North America.

While phylogenetic analysis recovered robust support for the troodontid status of WDC DML001, intraclade topology was sensitive to the inclusion of recent taxa such as *Mei*. This likely reflects a poor understanding of character transformation between basal paravians and derived troodontids. Further description of WDC DML001 may contribute to resolving this issue.

Finally, we note that WDC DML001 lacks arboreal specializations. Limb proportions, pedal phalangeal proportions, and flexor tubercle morphology are all consistent with a terrestrial lifestyle. WDC DML001 provides evidence that the oldest deinonychosaurs were not arboreal, consistent with a terrestrial origin for avian flight.

## Acknowledgements

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## References

- Hartman, S. 2000. Primary and caudal feathers as locomotor adaptations in maniraptoran theropods. *Journal of Vertebrate Paleontology*, Vol. 20, Supplement to No. 3, pp. 47A.
- Lovellace, D. 2004. Taphonomy and paleoenvironment of a Late Jurassic dinosaur locality in the Morrison Formation of East-Central Wyoming. *Journal of Vertebrate Paleontology*, Vol. 24, Supplement to No. 3, pp. 85A.
- Xu, X., Norell, M.A., Wang, X.J., Makovicky, P.J., and Wu, X.-c. 2002. A basal troodontid from the Early Cretaceous of China. *Nature*, Vol. 415: 780-784.
- Xu, X., and Norell, M.A. 2004. A new troodontid dinosaur from China with avian-like sleeping posture. *Nature*, Vol. 431: 838-841.