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THE MIDDLE-TO-LATE JURASSIC TERRESTRIAL TRANSITION: NEW DISCOVERIES FROM THE SHISHUGOU FORMATION, XINJIANG, CHINA

by

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THE terrestrial vertebrate record of the period between the well-known faunas of the Lower and Upper Jurassic is one of the most poorly known in the Mesozoic. This was a critical time in the evolution of terrestrial vertebrates, witnessing the basal divergences within several major groups of living tetrapods (mammals, squamates, frogs, salamanders, turtles), which were greatly affected by the breakup of Pangea that began about this time. Two areas in China preserve faunas well represented by articulated skeletons from this transitional period, the upper and lower Shaximiao Formations in Szechuan and the Shishugou Formation of northern Xinjiang. The Szechuan formations have limited outcrops to prospect for fossils, but the Shishugou Formation is well exposed over a 90 km x 20 km area in the center of the Junggar Basin, west of Mongolia in the Gobi Desert. However, its remoteness has hindered collecting efforts.

Fossils were first discovered in the Shishugou Formation in 1928 by an expedition led by Sven Hedin (Young 1937). Exploration of the Shishugou Formation in the 1970s and 1980s by the Institute of Vertebrate Paleontology and Paleoanthropology and the Chinese Canadian Dinosaur Project (Grady 1993; Dong 1994) resulted in the discovery of several important fossils (e.g., the theropods *Monolophosaurus* and *Sinraptor,* the sauropods *Bellusaurus*, *Mamenchisaurus*, and *Klamelia*, the tritylodontid *Bienotheroides*, and abundant material of the turtle *Xinjiangchelys* and the crocodyliform *Sunosuchus*), but many areas were left unexplored. Our expeditions from 2001-2005 amassed the largest collection of fossils from this formation including hundreds of associated skeletons, and produced the first radiometric dates. Most of the collections are from Wucaiwan (including Pingfengshan), but significant collections were also made from

Jiangjunmiao (stegosaurs, ornithopods) and Konglonggou (*Bellusaurus*, microvertebrates).

The Shishugou Formation preserves a faunal transition that has been interpreted as comprising separate Middle Jurassic and Late Jurassic faunas. For example, brachyopoid labyrinthodonts and the sauropod *Klamelia* are common in the lower fauna but disappear in the upper fauna, and the sauropod *Mamenchisaurus* is known only from the upper fauna. Based upon this faunal difference the lower part of the Shishugou formation has been identified as a separate formation (the Wucaiwan Formation) by Zhao *et al*. (1987), a distinction cited in several later papers (e.g., Dong 1994). However, we have been unable to identify a clear lithostratigraphic distinction accompanying the faunal change and therefore we prefer to use the term Shishugou Formation in reference to the unconformity-bounded sequence that occurs between the Middle Jurassic Xishanyao Formation and the Lower Cretaceous Tugulu Group (Eberth *et al*. 2001).

We encountered 9 bentonites and 8 tuff zones in a detailed stratigraphic study of the complete Shishugou Formation (378 m) exposed at Wucaiwan. Bentonites occur through 310 meters of section from 41 to 351 m above the base, whereas prominent, meter-scale tuff beds are limited to 194 m of section in the upper portion of the formation (157 to 351 m above the base). This same pattern -- thin bentonites in both the lower and upper beds and prominent tuffs in the upper beds -- is revealed in a partially exposed but fossiliferous section at Jiangjunmiao, 90 km east of Wucaiwan. X-ray fluorescence analysis of seven bentonites and tuffs collected from Wucaiwan indicates that geochemical fingerprinting correlation of these rocks is not possible. Single-crystal, total-fusion $^{40}Ar/^{39}Ar$ ages on sanidine extracted from the stratigraphically lowest

bentonite (B-1; 41 m above the base of the formation) and the uppermost tuff (T-4; 351 m above the base of the formation and 27 m below the unconformable contact with ?Cretaceous eolian beds) indicates that the Shishugou Formation straddles the Middle-Upper Jurassic boundary. These chronostratigraphic data corroborate previous biostratigraphic assessments for the age of these beds, and also suggest that the stratigraphically-limited faunal change that we have recorded in the middle of the Wucaiwan section is not an artifact of an unconformity.

Alluvial fan and alluvial plain depositional environments in the lower portion of the formation at Wucaiwan and Jiangjunmiao give way up-section to caliche- and tuff-rich alluvial and paludal deposits, indicating an increase in explosive volcanism and seasonal aridity, and a lowering of depositional slope throughout. These temporally constrained patterns of environmental change may ultimately be correlable with independent oxygen isotope data from the marine Middle-Late Jurassic transition in Europe, which indicate a pronounced cooling event at the end of the Middle Jurassic followed by a return to a warm climate at the beginning of the Late Jurassic (Dromart *et al*. 2003).

The lower part of the formation is dominated by sauropods and brachyopoid labyrinthodonts. At Wucaiwan the lower beds have produced a new sphenosuchian (Clark *et al*. 2004), *Junggarsuchus sloani*. This taxon shares several features with crocodyliforms that are lacking in other "sphenosuchians" and indicates that this latter group is paraphyletic. Wucaiwan also produced a fragmentary specimen of one of the oldest pterodactyloid pterosaurs (Andres and Clark 2005). At Konglonggou we re-opened the quarry that had produced abundant isolated elements of the enigmatic sauropod

Bellusaurus (Dong 1990) and collected hundreds of new specimens, including new cranial elements. A nearby locality that had produced a single jaw of the basal mammal *Klamelia* was screen washed and produced a microfauna including a squamate, docodont mammal teeth, and isolated teeth of actinopterygians, dipnoans, and crocodyliforms.

Fossils are more abundant in the upper part of the formation and the fauna is more diverse. Tritylodontids are common, and at least two species of *Bienotheroides* are present. At Wucaiwan we discovered three sites at which multiple theropod dinosaur skeletons occur. These medium sized theropods include at least two taxa, one of which is a new, basal tyrannosauroid bearing a double crest on its skull (Xu *et al*. in press). A second new theropod shares several similarities to alvarezsaurids. Ornithopods are well represented and include complete skeletons of the poorly known *Gongbusaurus wucaiwanensis* and a second, undescribed taxon. Nearly complete skeletal material was recently collected of the oldest and most primitive ceratopsian (Xu et al. submitted), which shares features with pachycephalosaurians and *Heterodontosaurus*. Small shartegosuchid crocodyliforms of at least two taxa are abundant as are xinjiangchelyid turtles. Ankylosaur and stegosaur material is more limited but is present. A new species of rhamphorhynchid pterosaur is represented by a crushed skeleton including the skull and much of the postcranial skeleton (Andres and Clark 2005).

The three theropod bonebeds include multiple, small-theropod taxa, with specimens arranged in semi-stacked successions of complete-to-partially-disarticulated skeletons. One site includes five individuals of similar size (c. 2-3 m total length) associated with a massive, clayey siltstone matrix and exhibiting some vertically oriented skeletal elements . A few tens of centimetres lateral to the specimens the host sediment

remains compositionally unchanged but exhibits fine laminations and horizontally-oriented roots, suggestive of a paludal (wetland) setting in which sediment accumulated over many years.

The massive sediment associated with the skeletons indicates that the host sediment was bioturbated, destroying the original fine sedimentary structures. Partial disarticulation of some of the skeletons suggests subaerial exposure or trampling, and the vertical orientation of some articulated remains indicates that the host sediment had semi-fluid properties as some of the specimens accumulated. The presence of different kinds of theropods arranged in stratigraphic skeletal successions suggests that these deposits originated as predator/scavenger traps rather than mass mortality assemblages. The combined data indicate: (1) small theropods frequently became mired in quickmud in these wetlands; (2) mired individuals struggled and/or were trampled; and (3) trapped bodies or carcasses attracted other small theropods, which subsequently became mired and died.

These new fossil discoveries and radiometric dates will allow for more precise dating of correlative faunas in Asia once the appropriate comparisons are completed, providing a view of the Middle-to-Late Jurassic transition in Asia. The Toutunhe Formation and the overlying Qigu Formation in the southern Junggar Basin are approximately correlative with the Shishugou Formation but have produced mainly small specimens (Maisch *et al*. 2003; but see Dong 1993). The upper Shishugou fauna is similar to those of the Shar Teeg locality in Mongolia (Gubin and Sinitza 1996) and the Balabansai Svita of the Fergana Valley in Khirghizia (e.g., Averianov 2001). The well-known faunas of the lower and upper Shaximiao formations of Szechuan have been

considered slightly older than those of the Shishugou Formation (Chen 1996) but show a similar faunal change.

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