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A new specimen of the ornithischian dinosaur *Haya griva*, cross-Gobi geologic correlation, and the age of the Zos Canyon beds

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ABSTRACT

Although Mesozoic fossils are quite common in the Gobi Desert of Central Asia, it is often difficult to correlate among different localities because of a dearth of rocks amenable to absolute dating. Specifically, correlating between the eastern Gobi Desert and more western localities has been challenging. Here we give a Santonian-Campanian age for the enigmatic Zos Canyon beds in the Nemegt basin. This is based on the occurrence of the primitive ornithopod dinosaur *Haya griva* at both eastern Gobi exposures of the Javkhlant Formation and the Zos Canyon locality.

INTRODUCTION

The Gobi Desert of Mongolia and northern China encompasses over 1.23 million square kilometers and is one of the richest areas in the world for the discovery of Mesozoic vertebrates. Preeminent among these are the remains of dinosaurs. The first dinosaurs to be collected in this area were found by field parties of the American Museum of Natural History during what have become known as the "Central Asiatic expeditions" (Andrews, 1932). In intervening years, Mongolian, Chinese, Russian, Polish, Canadian, Belgian, Japanese, Korean, and American Museum of Natural History paleontologists have made extensive collections over a broad swath of territory. Most of the fossil- producing rocks in the Gobi Desert lack sediments amenable to radiometric dating (tuffs and detrital zircons). Furthermore, at least for the later Mesozoic,

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they lay in the magnetostratigraphic "Cretaceous quiet zone" (Ogg et al., 2004, Gradstein et al., 2012). These factors have made it difficult to empirically date and stratigraphically correlate localities that are often geographically broadly separated across the Gobi.

Joint expeditions carried out by the American Museum of Natural History and the Mongolian Academy of Sciences (MAE) starting in 1990 have explored fossil localities in much of the Gobi Desert. In 1991, MAE expeditions traveled to the white to reddish-brown beds of the Upper Cretaceous Javkhlant Formation in the eastern Gobi Desert Dorngobi Aimag, Mongolia (fig. 1). Although Russian and Mongolian paleontologists are known to have visited the site (Dashzeveg, personal commun.; Sochava, 1975; Martinson, 1982), we could find no record of Russian collections or publications on vertebrate fossils from this locality. Over several field seasons these expeditions amassed a collection of over a thousand vertebrate specimens. These include the dinosaurs *Yamaceratops dorngobiensis* (Makovicky and Norell, 2006) and *Haya griva* (Makovicky et al., 2011), as well as a bird egg and embryo (Balanoff et al., 2008; Varricchio et al., 2015), several other dinosaurs, lizards, dinosaur eggs, and mammals. Eberth et al. (2009) discussed the age and geology of this locality and determined that these beds lie conformably above the Cenomanian-Santonian Bayan Shire Formation. Each of these formations has a characteristic and nonoverlapping dinosaur fauna.

In 1992, MAE field parties, returning to Ulaanbaatar, made a short visit to the Zos Canyon locality (fig. 1). No identifiable remains were found; however, bone was abundant. Over several years MAE teams returned to the Zos Canyon locality repeatedly. Although vertebrate fossils are far from plentiful, multiple specimens of dinosaurs, mammals, turtles, and notably crocodilians (Pol and Norell, 2004a, 2004b) have been recovered.

One of these specimens, IGM (Geological Institute of the Mongolian Academy of Sciences, Ulaanbaatar, Mongolia) 100/3181, was collected by Mark Norell and Guillermo Rougier in the flats about 100 m north of the Red Rum sublocality (fig. 14). Unfortunately, most of the specimen had eroded; however, after preparation it was apparent that it is a small "hypsilophodontid" (or basal ornithopod sensu Butler et al., 2008, or basal neornithischian sensu Boyd, 2012) dinosaur that bears many anatomical similarities to the multiple specimens of *Haya griva* found at the eastern Gobi location of Shine Us Khudag (Javkhlant Formation) ~600 km away from the Zos Canyon locality.

We are currently preparing a larger treatment on the anatomy and phylogenetics of *Haya* (Barta and Norell, in prep.). The intent of this paper is to show evidence of a biostratigraphic correlation among the eastern and western Gobi localities.

DESCRIPTION OF IGM 100/3181

Cranium

IGM 100/3181 (fig. 2) is a fragmentary skeleton including the left side of the cranium (fig. 3), two loose teeth (fig. 4), a radius and ulna (fig. 5), several carpals, phalanges, and unguals (fig. 6), and a partial dorsal vertebral series and associated ribs (figs. 7, 8). Although in articulation, most of the specimen had eroded prior to discovery and excavation.

FIG. 1. Map of Mongolia showing the relative positions of the Javkhlant Formation exposures and Zos Canyon beds (near Ukhaa Tolgod). Zos Canyon is 7 km northwest of the Ukhaa Tolgod locality. See Pol and Norell (2004a: fig. 1) for detail.

The cranium was split down the sagittal midline during erosion; only the left tooth row is preserved. In all aspects of its anatomy the cranium is nearly the same as the holotype of *Haya griva* (IGM 100/2017) and the material referred to that species (see Makovicky et al., 2011). The cranium measures 83 mm long from the anterior tip of the premaxilla to the posteroventral corner of the quadratojugal.

The premaxilla is crushed, obscuring contact with the nasals. Although much of what is preserved is fragmentary, it is clear that the premaxilla is dorsoventrally high and forms the anterior and ventral borders of the narial cavity. The subnarial process gently curves posteriorly and may have contacted the anterior process of the lacrimal dorsally. The tooth row contains five alveoli, as in the type specimen, although only three teeth are preserved. On the anterodorsal tip of the premaxilla there are small nutrient foramina as in the type.

The frontal is arched, giving the skull a domed appearance above the orbit. It contacts the parietal posteriorly along a transverse suture. Contact with the nasal occurs just anterior to the preorbital bar as in the type. The supraorbital rim is rugose posteriorly just anterior to the postorbital contact.

FIG. 2. IGM 100/3181, a partial skeleton of *Haya griva*.

As in the type, the lacrimal forms a portion of the preorbital bar and the maxilla-jugal ramus is oriented along an anterodorsal-posteroventral axis. It contacts the maxilla ventrally just anterior to the maxilla-jugal contact. The anterior ramus overlaps the maxilla above the antorbital fossa. The descending ramus contributes to the preorbital bar and is laterally thick and contains a shallow but distinct longitudinal groove on its posterior surface. The posterior ramus forms the anterior border of the orbit.

The prefrontal also forms part of the preorbital bar medial to the descending ramus of the lacrimal. The prefrontal is extensively exposed on the dorsal surface of the skull where it forms part of the anterodorsal boundary of the orbit. Near the contact with the palpebral there is a small foramen just posterior to the level of the preorbital bar on the dorsal surface of the skull. Anteriorly there is a small contact with the nasal, and the posterior ramus extensively contacts the frontal, lying in a slot dorsal to the orbit.

A widely distributed feature of "basal ornithopods" is the presence of a large triradiate palpebral bone that lies in the anterodorsal corner of the orbit. IGM 100/3181, like the *Haya* holotype, bears a well-developed palpebral. In IGM 100/3181 the anterior and dorsal processes are small. The dorsal process is recurved and contacts the prefrontal. The anterior process is straight and pointed and contacts the prefrontal-lacrimal junction. This articulation is complex in that the anterior process is cuplike and adheres to the orbital rim. The posterior process is

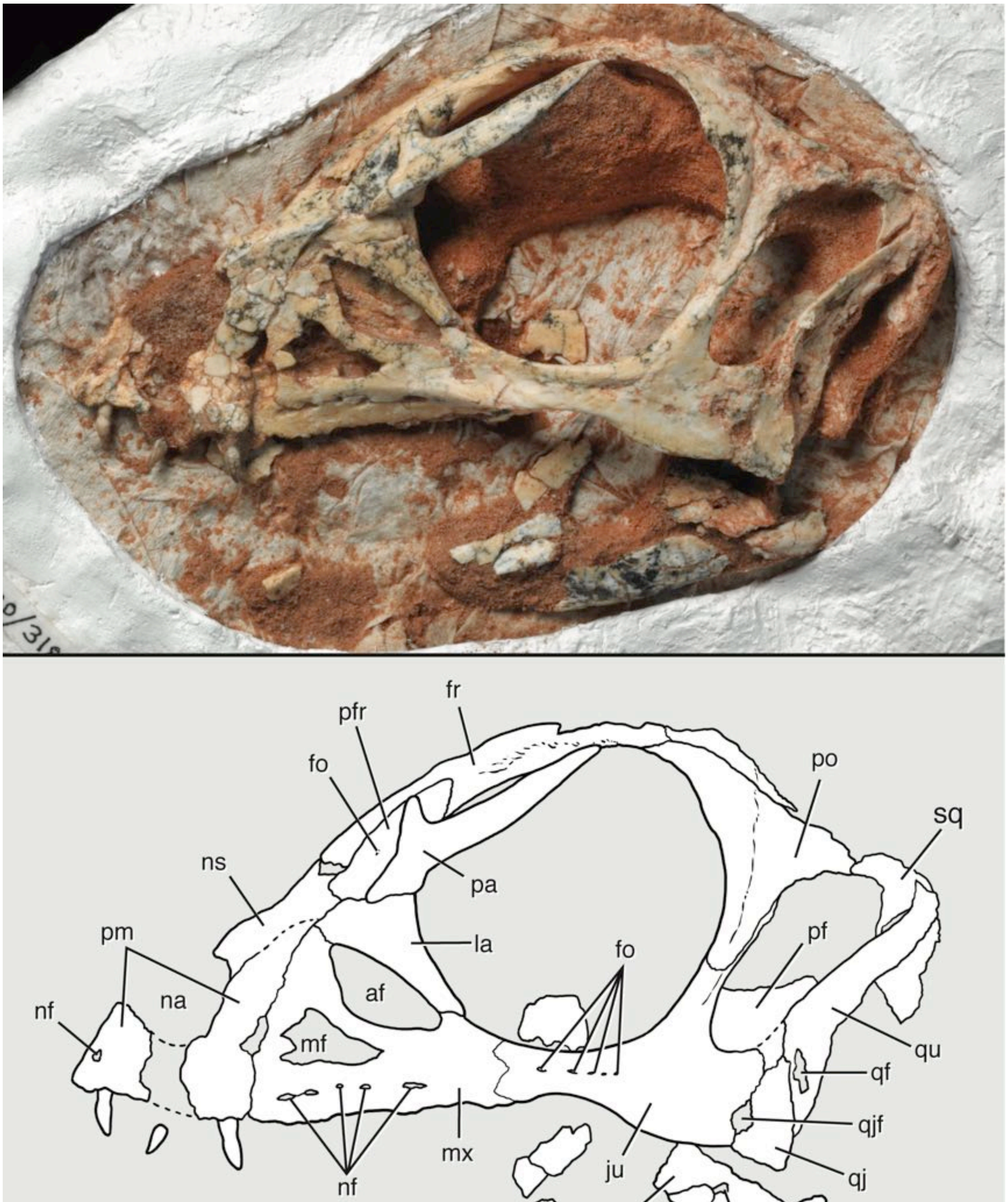


FIG. 3. The left side of the cranium of IGM 100/3181, with interpretive drawing. Abbreviations are listed in appendix 1.

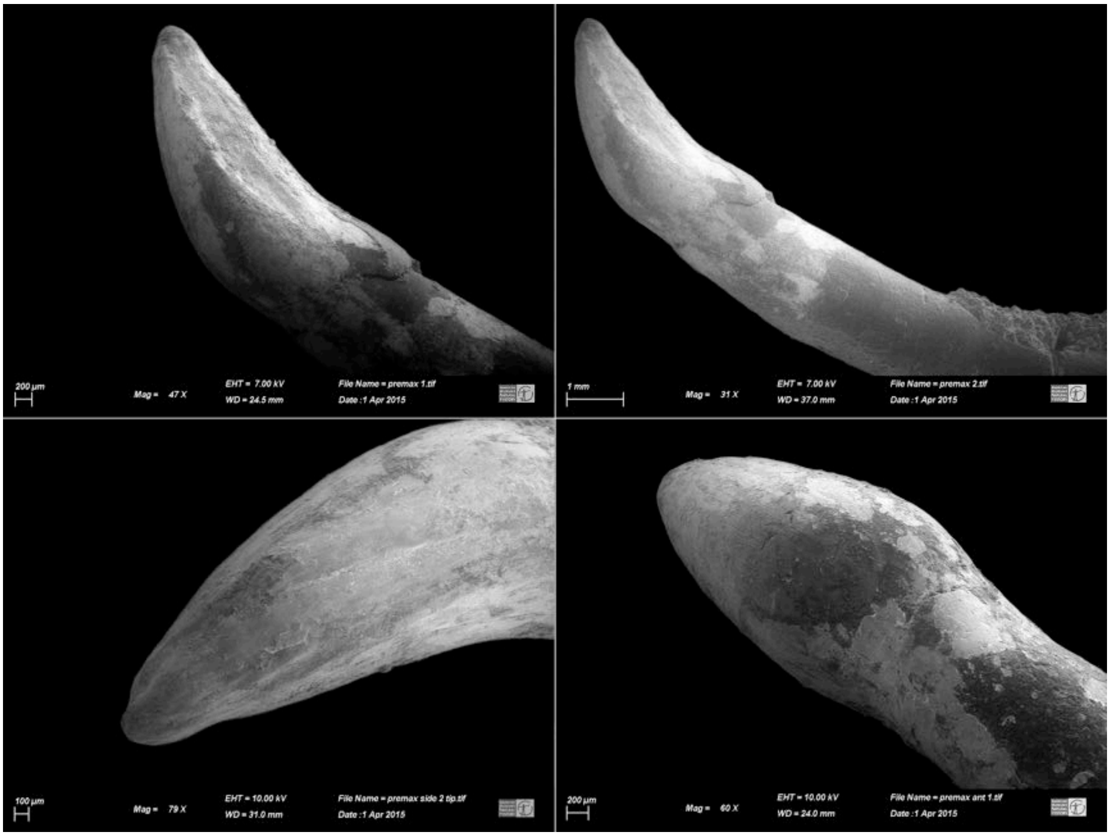
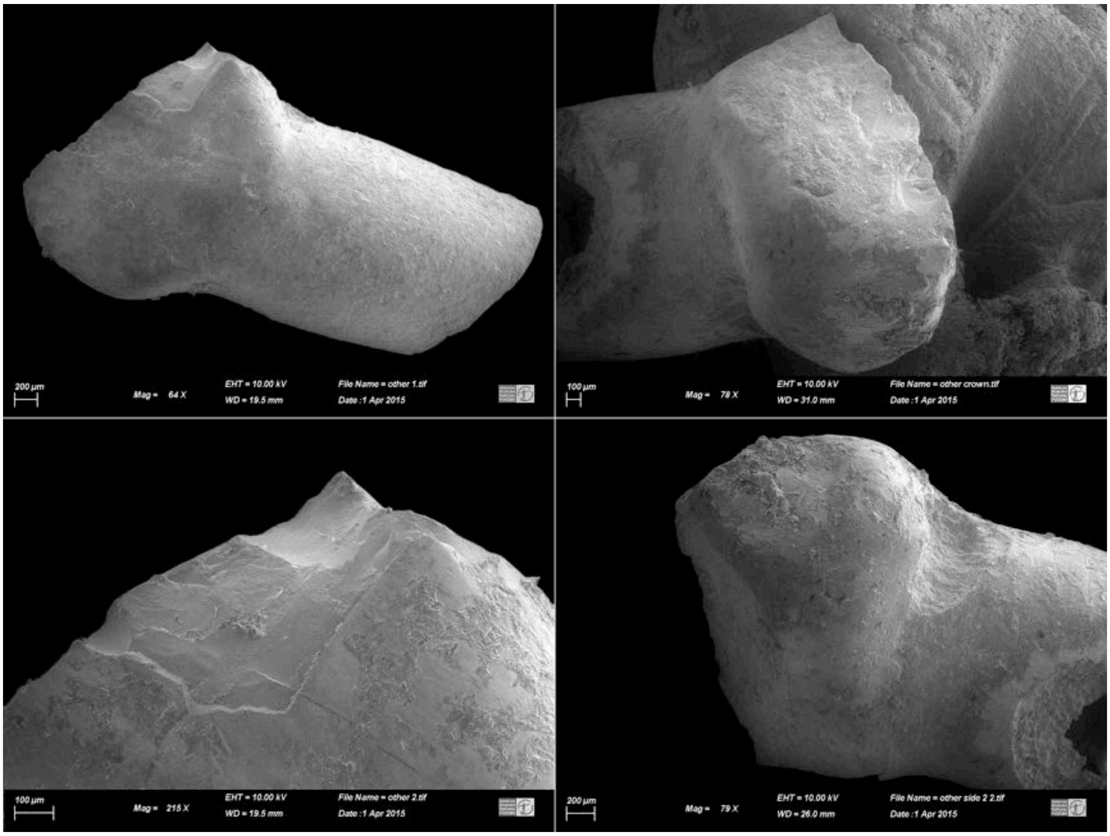


FIG. 4. **A.** Premaxillary tooth of IGM 100/3181 in mesial and distal views. Its precise orientation cannot be determined as it was found as float during preparation. **B.** Cheek tooth of IGM 100/3181. Its precise orientation cannot be determined as it was found as float during preparation, and is compatible with the morphology of both upper and lower teeth of referred *Haya* specimens.

long and sweeps dorsally, extending over 3/4 the length of the orbit, and terminates in a sharp point. The surface of the posterior process bears faint longitudinal striations.

The maxilla is fairly well preserved. It has a large, ventromedially projecting surface separated from the lateral surface of the maxilla by the buccal ridge above the tooth row. Posteriorly the buccal ridge merges with a corresponding ridge on the jugal ventral to the orbit. This surface is punctuated with a row of five nutrient foramina parallel to the tooth row and the buccal ridge. No complete maxillary teeth are preserved; however, about eight or nine tooth alveoli are preserved. The lateral surface of the maxilla is perforated by a large antorbital fenestra and a smaller, more anterior maxillary fenestra. Although there is some damage to the boundaries of these fenestrae, it is clear the long axis of the antorbital fenestra slants anterodorsally-posteroventrally. As in the holotype, an osseous lamina forms the floor of the antorbital fenestra. The smaller triangular maxillary fenestra lacks an osseous floor.

As in most dinosaurs the postorbital is triradiate. The orbital process is thin and pointed and contributes to the arc-shaped postorbital bar, giving the orbit a distinctly round shape. The rim along the orbit is slightly everted, and a small bump projects into the orbit as is typical of



Haya griva and many other “hypsilophodontids” (such as *Zephyrosaurus*, *Orodromeus,* and immature *Thescelosaurus*, among others). It articulates with the postorbital process of the jugal along a scarf joint. The lateral surface along the jugal ramus exhibits a vertical depression or groove. The posterior ramus contacts the squamosal to form a bridge between the supratemporal and infratemporal fenestrae.

The jugal is an extensive platelike bone that forms most of the suborbital lateral surface of the skull. Its anterior process extends ventral to the orbit to meet the maxilla where it is bifurcated to receive the posterior or jugal process of the maxilla. This anterior process is concave dorsoventrally, becoming more so at the postorbital bar. A suborbital depression on the lateral surface of the anterior process is enhanced by a distinct ridge lying just anterior to the postorbital bar. This ridge continues onto the postorbital process to define the posteroventral corner of the orbit. Several small foramina lie in the lateral depression. In ventral view there is a distinct ventrally oriented shelf that lies posterior to the tooth row and is continuous with the shelf on the maxilla described above. Posterior to the postorbital bar the jugal is dorsoventrally expanded in lateral view ventral to the infratemporal fenestra. Posteriorly, this process contacts the quadratojugal along a vertical suture that contains the quadratojugal foramen. The postorbital process extends posterodorsally to form the posterior margin of the orbit. Dorsally it underlies the postorbital about halfway along the postorbital bar. Posteriorly and together with

FIG. 5. The radius (*top*) and ulna (*bottom*) of IGM 100/3181.

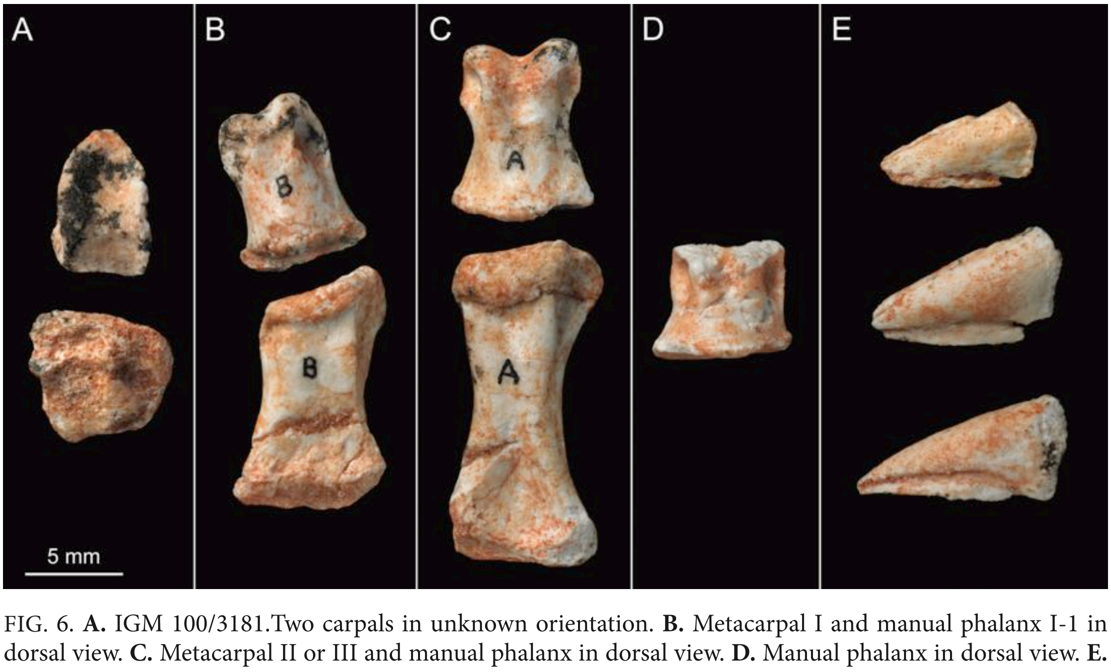


FIG. 6. **A.** IGM 100/3181.Two carpals in unknown orientation. **B.** Metacarpal I and manual phalanx I-1 in dorsal view. **C.** Metacarpal II or III and manual phalanx in dorsal view. **D.** Manual phalanx in dorsal view. **E.** Three ungual phalanges in partial dorsal view.

FIG. 7. Ventral view of the preserved dorsal vertebrae of IGM 100/3181. Anterior is to the right.

FIG. 8. Dorsal view of the dorsal vertebrae showing the latticelike ossified tendons in IGM 100/3181. Anterior is to the right.

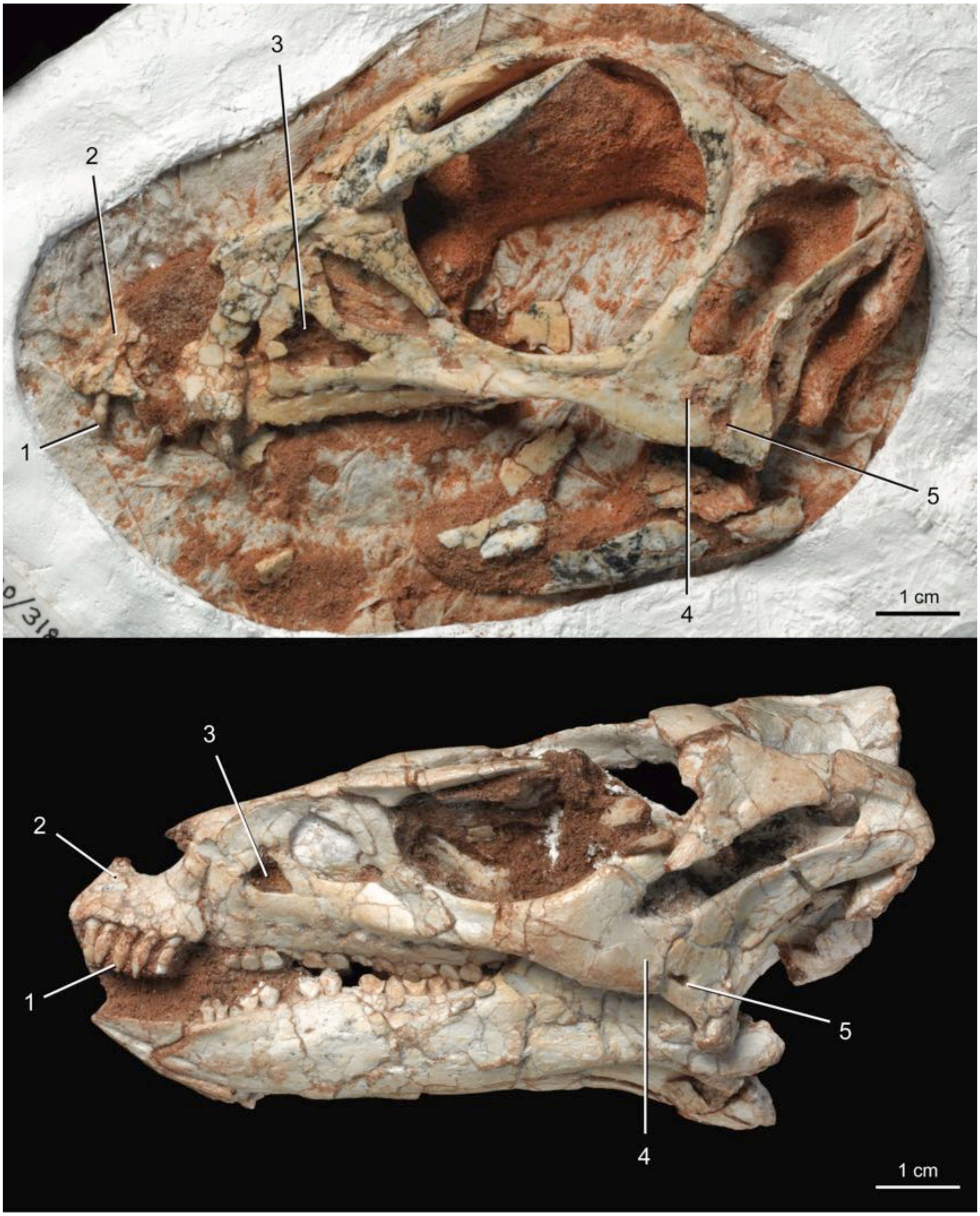


FIG. 9. **A.** Comparison of IGM 100/3181 (top) with the holotype of *Haya griva* (IGM 100/2017, bottom). Shared diagnostic characters (Makovicky et al., 2011) are: (1) homodont unserrated premaxillary teeth, (2) the lack of a rugose rhamphothecal pad on the anterior surface of the premaxilla, (3) the presence of a triangular maxillary fenestra, (4) a jugal with a bifurcated (forklike) posterior ramus where it abuts the quadratojugal, (5) the presence of a quadratojugal foramen.

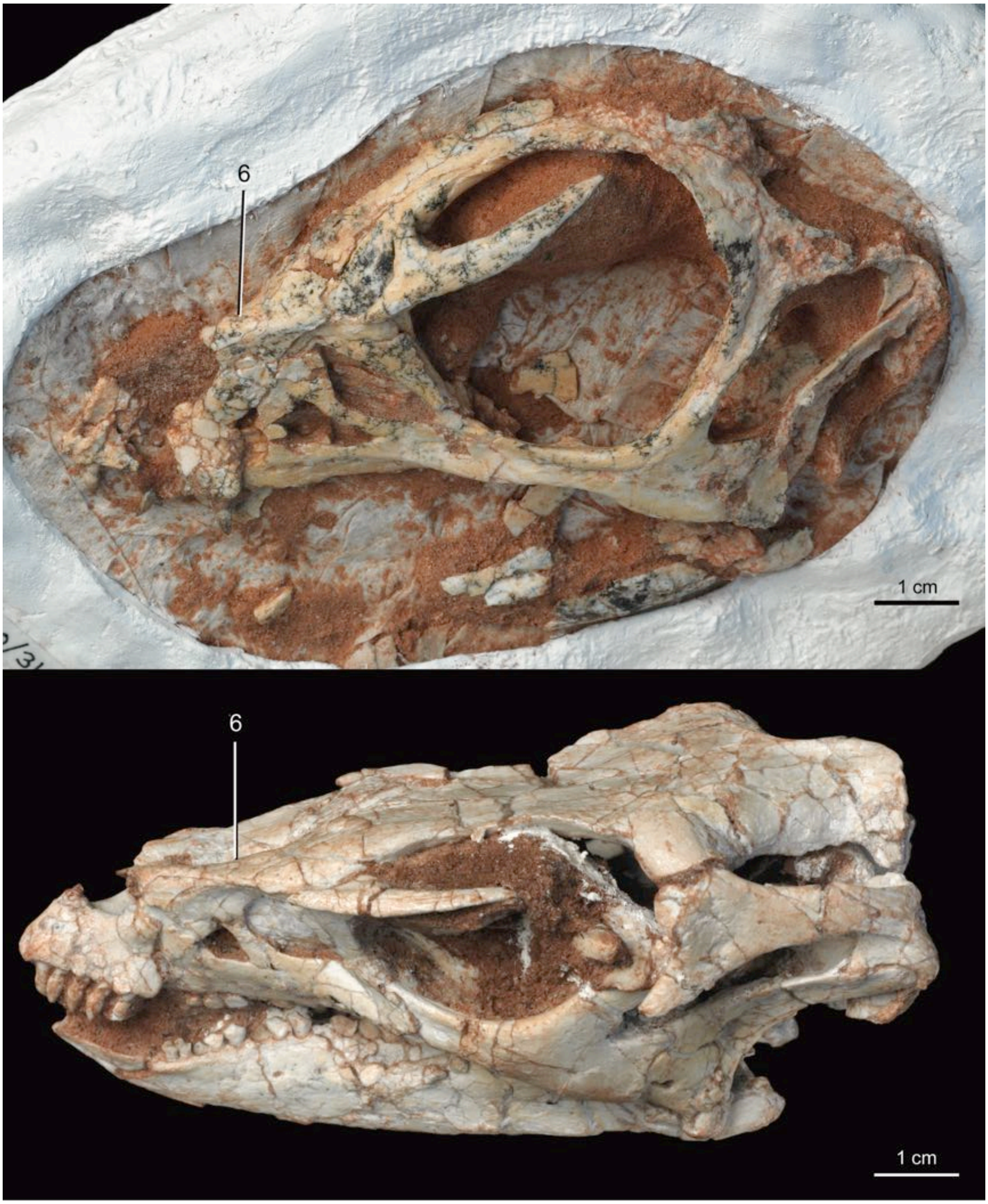


FIG. 9. **B.** Shared diagnostic character (6) a shallow depression along the midline nasal suture anterior to the orbits on the dorsal surface of the skull.

FIG. 10. Looking south from the base of the Zos Canyon section. The arrow indicates the Red Rum sublocality.

the postorbital, it defines the anterior margin of the somewhat quadrangular-shaped infratemporal fenestra.

The quadratojugal is so damaged that little information can be garnered, but beyond that it appears to form the posteroventral corner of the cranium when viewed laterally. The quadrate is narrow and bows anteriorly in lateral view. It forms nearly the entire posterior boundary of the infratemporal space. The lateral surface contains a longitudinal depression that mirrors the shape of the element. The anterior boundary of this depression is more robust than the posterior. Within this there are a few small pockmarks, one of which may represent the quadrate foramen. A broad pterygoid flange extends anteromedially and forms a deep sulcus at its junction with an anterolaterally projecting surface. The squamosal articulates with the quadrate in this depression.

The squamosal articulates with the tapering dorsal or squamosal process of the quadrate along the dorsoposterior angle of the infratemporal fenestra. This articulation consists of dorsal and posterior processes of the squamosal that form a depression to receive the quadrate.

The mandible is very poorly preserved. Although the dentary, angular, and surangular are identifiable, they retain little useful information apart from the fact that within the surangular there is a small foramen. Posterior to these bones lies the retroarticular process.

FIG. 11. Looking south at the basalmost fluvial red sands at Zos Canyon.

Aside from the premaxillary teeth that are associated with the skull, two other loose teeth were found during preparation. One of these is identical to the premaxillary teeth (fig. 4A), and the other is a maxillary or dentary tooth (fig. 4B). The premaxillary teeth are long and conical with recurved tips. The premaxillary teeth have bulbous bases and lack any serrations on their faint carinae. The enamel appears to have minute striations.

The cheek tooth is typical of "hypsilophodontids" (i.e., low with a flat, inclined grinding surface). There is a marked constriction between the crown and tooth base. Because this is a loose tooth, it cannot be determined which is the labial or lingual surface.

Postcranium

The radius and ulna are very poorly preserved and the ends are extremely eroded (fig. 5). About the only thing that can be said is that the radius is round in cross section and the ulna is mediolaterally compressed and anteroposteriorly bowed. Several carpals, metacarpals, phalanges, and unguals are preserved (fig. 6); however, they are not described here, except to note that the morphology of metacarpal I (fig. 6B) is consistent with that of a referred specimen of *Haya griva*, IGM 100/2015 (Makovicky et al., 2011).

FIG. 12. Looking south toward Red Rum (arrow) at the intermediate white beds of Zos Canyon.

A series of nine dorsal vertebrae are preserved in articulation (fig. 7). Extending from these are poorly preserved corresponding ribs. Although the vertebrae are not completely exposed, it can be determined that there are ossified tendons that lie adjacent to the neural arches. These tendons extend across several vertebrae and are imbricated in a latticelike fashion (fig. 8). The vertebral centrae are heavily eroded; however, it can be ascertained that they are anteroposteriorly constricted and amphicoelous. They are very thin when viewed dorsally. All the vertebrae appear to exhibit a small ventral keel. This can best be observed in the sixth and seventh preserved vertebrae in the sequence (fig. 7).

DISCUSSION

Several characters that were used to diagnose *Haya* in the original description (Makovicky et al., 2011) can be identified in IGM 100/3181 (fig. 9). These include: (1) homodont unserrated premaxillary teeth, (2) the lack of a rugose rhamphothecal pad on the anterior surface of the premaxilla, (3) the presence of a triangular maxillary fenestra, (4) a jugal with a bifurcated (fork-like) posterior ramus where it abuts the quadratojugal, (5) the presence of a quadratojugal foramen, and (6) a shallow depression along the midline nasal suture anterior to the orbits on the dorsal surface of the skull.

FIG. 13. The Red Rum sublocality, looking west-southwest.

The differential diagnosis of *Haya griva* is based on its possession of a unique suite of characters, some of which may represent autapomorphies (Makovicky et al., 2011). Specimen IGM 100/3181 bears at least six features that are identical to those of *Haya griva*. Whatever the ultimate position of *Haya* is in the ornithischian tree and however these characters optimize (as autapomorphies or local autapomorphies or as unique suites of character states), we are confident that the character information provided by IGM 100/3181 is sufficient that the specimen will also group exclusively with *Haya griva*. We therefore can strongly state that this material is referable to that taxon.

In 1993, MAE paleontologists discovered the Ukhaa Tolgod fossil locality (Dashzeveg et al., 1995; Dingus et al., 2008). This locality is considered one of the richest localities in the world with an impressive number of specimens both in abundance and diversity. During excavations at Ukhaa Tolgod, frequent sojourns to Zos Canyon resulted in a small collection, much of it yet unstudied.

Dingus et al. (2008) carefully documented the geology of the Ukhaa Tolgod beds and suggested a Campanian age for these sediments. This is in general agreement with previous studies of this and other Djadokhta localities (Lillegraven and McKenna, 1986; Averianov, 1997; Gao and Norell, 2000; Dashzeveg et al., 2005). These correlative Djadokhta localities

FIG. 14. Looking northwest from the Red Rum sublocality toward the discovery site (arrow).

include the red sandstones at Bayn Dzak (Berkey and Morris, 1927) and the white sands of Tugrikin-Shireh (Fastovsky et al., 1997), both in the Middle Gobi near the town of Dalandzadgad. However, since beginning work in the Nemegt basin, the age of the Zos Canyon beds has always been a conundrum.

The Zos Canyon beds themselves are topographically (i.e., altitudinally) higher than the Ukhaa Tolgod beds as they lie on the flanks of the southern slope of the Nemegt Ul (fig. 10). But they dip at an angle of about 14° to the south and hence superpositionally lie below the Ukhaa Tolgod beds. If one follows the section from Ukhaa Tolgod through either Gilvent or Zos Canyon Sayr it is clear that the section is continuous and there is no significant faulting or noticeable unconformities between the localities.

Lithologically, the Zos Canyon locality is highly variable. At its base against the mountains the sediments are reddish and primarily fluvial sands with small pebbles and developed caliches (fig. 11). These sediments produced the canyon's two published crocodilian specimens, *Zosuchus* and *Zaraasuchus* (Pol and Norell, 2004a, 2004b). Up-section and in the middle of the basin are thick channel sands with disarticulated bones of large dinosaurs (including theropods), turtles and advanced (probably eusuchian) crocodilians (fig. 12). Occasional pieces of fossil wood are also found in these whitish beds. Above these, just to the north of Zos Sayr, is the Red Rum sublocality (fig. 13). This locality is the most prolific of the Zos Canyon sublocalities. The rocks here are distinctly different from Djadokhta rocks at Ukhaa Tolgod and also unlike those that are down-section at Zos Canyon. They lack the aeolian component, are less sandy, and except for the sediments around the Red Rum sublocality, are much more fluvial (fig. 14). These sediments also have a very different faunal composition than Ukhaa Tolgod.

The Javkhlant beds at Shine Us Khudug that produced the *Haya griva* type material have been assigned a Santonian-Campanian age based on, among other things, ostracods (Jerzykiewicz and Russell, 1991; Khand et al., 2000; Jerzykiewicz, 2001). Therefore, because of the occurrence of the basal ornithopod *Haya griva* at both sites we recognize the Zos Canyon beds as coeval with the Javkhlant beds at Shine Us Khudug and temporally correspondant in Santonian-Campanian age. This represents a continuation of conformable stratigraphic sequence in the Upper Cretaceous depositional system of the Gobi Desert. Additionally, this cross-Gobi correlation further supports the presence of a continuous rock record from the bottom of the Bayn Shire Formation to the top of the Djadokhta Formation.

CONCLUSIONS

As a result of our study of IGM 100/3181, we have concluded: (1) IGM 100/3181 is referable to *Haya griva*, a small ornithischian ornithopod dinosaur previously only known from the Javkhlant Formation in the eastern Gobi Desert, Dorngobi Aimag, Mongolia; (2) The Zos Canyon beds conformably underlie the Campanian Djadokhta Formation at Ukhaa Tolgod, Omnogov Aimag, Mongolia; (3) By biostratigraphic correlation, the Zos Canyon beds are considered to be coeval with the Javkhlant beds at Shine Us Khudug; and (4) The Zos Canyon beds are Santonian-Campanian in age and older than the Ukhaa Tolgod beds.

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APPENDIX 1

Abbreviations

af	antorbital fenestra
an	angular
fo	foramina
fr	frontal
ju	jugal
la	lacrimal
mf	maxillary fenestra
mx	maxilla
na	naris
nf	nutrient foramina
ns	nasal
pa	palpebral
pf	pterygoid flange of quadrate
pfr	prefrontal
pm	premaxilla
po	postorbital
qf	quadrate foramen
qj	quadratojugal
qjf	quadratojugal foramen
qu	quadrate
sa	surangular
sf	surangular foramen
sq	squamosal

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