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The first occurrence of the enigmatic archosaur *Crosbysaurus* (Heckert 2004) from the Chinle Formation of Southern Utah

ABSTRACT - Originally identified as an ornithischian dinosaur, teeth assigned to *Crosbysaurus* has been found in New Mexico, Arizona, and the type locality in Texas. The genus has been reassessed by other workers in light of revelations about the postcrania of another putative Triassic ornithischian, *Revueltosaurus*. The understanding of Triassic dental faunas has become more complicated by the extreme convergence between pseudosuchian archosaurus and ornithischian dinosaur dental morphologies. We report here on a new specimen of *Crosbysaurus* from the Petrified Forest Member of the Chinle Formation at Comb Ridge in southeastern Utah. This new specimen is assigned to *Crosbysaurus* on the basis of the unique compound posterior denticles, mediolateral width, and curvature. While this specimen, MNA V10666, does not help resolve the affinities of *Crosbysaurus* it does represent an approximately 250 kilometer extension of the geographic range of this taxon. This is the first record of this taxon in Utah and as such it represents the northernmost known record of *Crosbysaurus*. This indicates that *Crosbysaurus* was not limited to the southern area of Chinle/Dockum deposition but instead was widespread across the paleoriver systems of the Late Triassic in western Pangea. The specimen we report on here was found in close association with a typical Late Triassic Chinle fauna, including phytosaurs, metoposaurs, and dinosauriforms.

INTRODUCTION

When *Crosbysaurus* was first described by Heckert in 2004 the assumption was that it, like the better-known *Revueltosaurus*, was an ornithischian dinosaur. Several purported ornithischian tooth taxa were named, leading several authors to suggest that herbivorous dinosaurs were widespread across Pangea (Hunt and Lucas, 1994; Heckert 2002, 2004, 2005). This contrasted sharply with the previous views on ornithischian diversity and stood in sharp contrast with the non-dental fossil record of ornithischian diversity outside of the southern hemisphere.

This interpretation of the fossil record was challenged by Parker et al. (2005) with the discovery of the postcrania of *Revueltosaurus* from the Petrified Forest of Arizona. Not only did this revise how *Revueltosaurus* was seen but it called into question all of North America's supposed ornithischian dinosaurs from the Triassic Period (Irmis et al. 2006; see also Nesbitt et al., 2007). Without any supporting skeletal remains it was no longer parsimonious to assign "fabrosaur"-type teeth to any known dinosaur clade. While *Revueltosaurus* is now known from postcrania, other supposed ornithischians known from only teeth like *Tecovasaurus* and *Crosbysaurus* can only be identified as being either archosaurs or archosauriforms of uncertain affinity (Irmis et al., 2007*). While some authors have suggested that ornithischians were present in the Late Triassic of North America (Heckert 2005) virtually all authors are in

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Comment [2]: Heckert et al. (2012) also described teeth assigned to *Crosbysaurus* sp. from North Carolina

Heckert, A.B., Mitchell, J.S., Schneider, V.P. and Olsen, P.E., 2012. Diverse new microvertebrate assemblage from the Upper Triassic Cummock Formation, Sanford subbasin, North Carolina, USA. *Journal of Paleontology*, 86(2): 368-390.

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Comment [4]: Nesbitt, S.J., Irmis, R.B. and Parker, W.G., 2007. A critical re-evaluation of the Late Triassic dinosaur taxa of North America. *Journal of Systematic Palaeontology*, 5(2): 209-243.

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Comment [5]: I cite Irmis et al. as 2007 (when the print edition came out).

1 agreement that *Crosbysaurus* does not represent a dinosaur and instead is an archosauriform.
2 While this new record does not clarify the taxonomic affiliations of *Crosbysaurus* it does
3 significantly extend its range. Previous reports of *Crosbysaurus* have been limited to Texas (the
4 type locality), New Mexico, and Arizona (Heckert 2004). Comb Ridge in southeastern Utah is
5 approximately 245 kilometers away from the closest reported *Crosbysaurus* remains in the
6 Chinle Formation of Arizona.

7 In May of 2014 10 students from Mission Heights Preparatory High School traveled to
8 southeastern Utah to prospect the Chinle Formation exposed at Comb Ridge, as well as to open
9 a test pit at a possible metoposaur id temnospondyl site located by the first author in March. The
10 second author, accompanied by another student, discovered a rich locality to the south of the
11 metoposaur site. The second author and another student named this rich microsite "The Hills
12 Have Teeth." While combing the ground near the base of The Hills Have Teeth locality (MNA
13 Locality 1724) the second author discovered an unusual tooth, MNA V10666, to the west-
14 southwest of the main outcrop. This second locality has been designated MNA Locality 1725.
15 The students brought this tooth to the first author's attention. It is this specimen that we describe
16 here.

19 MATERIALS AND METHODS

21 **Abbreviations** - Mission Heights Preparatory High School, Casa Grande, Arizona
22 (MHPRO); Museum of Northern Arizona, Flagstaff, Arizona (MNA)

24 **Materials** - Standard paleontological hand tools were used to collect MNA V10666.
25 Geographic locality data were recorded via BackCountry Navigator Android Application running
26 on a Samsung Galaxy S4. All specimens were collected under Bureau of Land Management
27 paleontology permit UT14-001S issued to the first author and are curated at the MNA. Figures
28 and line drawings were produced using GIMP 2.8.4. Photos used for figures were obtained
29 using an Olympus E-500 DSLR camera. Specimen measurements were obtained using metal
30 sliding calipers.

32 RESULTS

34 Systematic paleontology

36 Reptilia Laurenti 1768
37 Archosauromorpha von Huene 1946
38 Archosauriformes Gauthier 1986
39 ?Archosauria Cope 1869

41 Referred material

43 MNA V10666, a single shed tooth crown.

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Locality and horizon

The locality, designated MNA 1725, is in San Juan County, Utah (Figure 1). The exact coordinates remain on file at the Museum of Northern Arizona. This locality, named The Hills Have Teeth, produced numerous partial and complete phytosaur and metoposaur teeth along with several dinosaur or dinosauromorph teeth. MNA V10666 was found approximately 4 meters west-southwest of The Hills Have Teeth as surface float. We presume it to have originated at The Hills Have Teeth. This is corroborated by the presence of phytosaur tooth fragments found close to MNA V10666 which the second author was able to connect with fragments collected at the main deposit at The Hills Have Teeth.

This area has not been mapped in detail but this portion of the Chinle Formation has been reported to be or correlate to the Petrified Forest Member (Bennett, 1955). Further work by the authors and others is ongoing and the relationships between the beds at Comb Ridge and other exposures of the Chinle Formation will be clarified in the near future. None the less it is clear that MNA V10666 originally was deposited near the base of the Chinle Formation as part of the earliest fauna recorded in the Comb Ridge area (Figure 2).

The precise fossil-bearing horizon where MNA V10666 has not been identified but the nearby outcrop consists of fine white to grey mudstones and siltstones interpreted by us as floodplain deposits. Based on the fossil deposits nearby it is likely that MNA V10666 originated from these floodplain deposits as well.

Description - MNA V10666 is a single nearly complete shed tooth. Since *Crosbysaurus* is known only from dental material it is not possible to confidently assign a tooth row position to the tooth. Heckert (pers. comm., 2014) suggested to the first author that this tooth may be from the premaxilla based on the relative robustness. The tooth itself is laterally compressed and antero-posteriorly expanded at the base tapering towards the apex. There is an obvious resorption pit at the base of the tooth and the tip is worn and broken (Figure 3). These data suggest that MNA V10666 is a shed tooth.

The tooth is 3.7mm from the base to the apically-most preserved point and 3mm antero-posteriorly. Mediolaterally the tooth measures 1 mm (Figure 3). The enamel is a light tan to mottled brown color, typical of many of the teeth from The Hills Have Teeth locality. The posterior edge of the tooth is curved posteriorly and has six equally spaced denticles. The basalmost denticle is approximately 0.3 mm in basal-apical height while the apical-most is 0.2 mm in height. Above the apical-most denticle is a thin ridge of enamel. Since the tooth has been worn and was shed during life additional denticles may have been present higher on the mesial side. This is not possible to evaluate at this time due to the premortem and postmortem wear of the tooth. The posterior denticles that are present appear to have possessed smaller accessory denticles. Most of these are worn but one denticle preserves four accessory denticles on the basal edge and three on the apical edge (Figure 4).

The anterior edge of the tooth is expanded 2 mm from the base of the tooth, approximately even with the level of the last posterior denticle. Very fine (<0.1 mm) denticles cover the anterior edge of this ridge which extends for 1 mm.

DISCUSSION

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Harshbarger, J.W., Repenning, C.A. and Irwin, J.H., 1957. Stratigraphy of the upper most Triassic and the Jurassic rocks of the Navajo Country. U.S. Geological Survey Professional Paper, 291: 1-74.

Repenning, C.A., Cooley, M.E. and Akers, J.P., 1969. Stratigraphy of the Chinle and Moenkopi formations, Navajo and Hopi Indian reservations Arizona, New Mexico, and Utah. Geological Survey Professional Paper, 521-B: 1-34.

Stewart, J.H., Poole, F.G. and Wilson, R.F., 1972. Stratigraphy and origin of the Chinle Formation and related Upper Triassic strata in the Colorado Plateau region. U.S. Geological Survey, Professional Paper, 690: 336.

Lucas, S.G., Heckert, A.B., Estep, J.W. and Anderson, O.J., 1997. Stratigraphy of the Upper Triassic Chinle Group, Four Corners Region. New Mexico Geological Society Guidebook, 48: 81-107.

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Differential Diagnosis

MNA10666 differs from most described Triassic tooth taxa in several important ways. It differs from the teeth of *Revueltosaurus*, the most commonly reported tooth taxon in the Late Triassic of North America, by being mediolaterally narrower than all published specimens of *Revueltosaurus* (Hunt, 1989; Heckert, 2002; Parker et al., 2005). The teeth of *Revueltosaurus* are also anteriorposteriorly broad compared to their apical-basal height. *Revueltosaurus* is now known from non-dental remains (Parker et al. 2005) and the tooth variation documented in the premaxilla, maxilla, and dentary do not match any teeth reported from *Crosbysaurus* (Irmis et al., 2006). This holds true for MNA V10666 as well; there appears to be no place in the dentition of *Revueltosaurus* for a tooth with the morphology of this specimen.

MNA V10666 differs from the putative Triassic ornithischian, *Tecovasaurus* (Hunt and Lucas, 1994), in several ways. The teeth of *Tecovasaurus* tend to be much shorter and broader as compared to this specimen specifically as well as *Crosbysaurus* generally. Anterior denticles in *Tecovasaurus* tend to be large and coarse while being more numerous than those on the posterior edge of the tooth (Heckert 2004). In MNA V10666 the posterior denticles are much coarser than the anterior denticles (Figure 3).

Another Triassic archosauriform, *Protecovasaurus lucasi* (Heckert 2004) differs from MNA V10666. The anterior and posterior denticles are roughly equivalent in size and number. In MNA the posterior denticles are both larger and more numerous than those on the anterior edge (Figure 3). No teeth reported for *Protecovasaurus* match the morphology seen in MNA V10666. Since non-dental fossils are not known for this or other possible ornithischians from the Triassic of North America it does not rule out positional or ontogenetic variation accounting for the morphological distance between MNA V10666 and these taxa. Given the homodonty present in most basal archosaurs and archosauriformes it is unlikely that any other teeth taxa published from the Late Triassic of North America are represented by MNA V10666.

MNA V10666 closely matches the published illustrations and descriptions of *Crosbysaurus* (Heckert, 2004). The complex posterior denticles coupled with the recurved nature of the tooth itself are diagnostic of the genus (Heckert, 2004). None the less several differences exist between MNA V10666 and all other published specimens which warrant some discussion.

Teeth referred to *Crosbysaurus* by other workers fall into two morphotypes: laterally compressed and highly recurved or basally wide and moderately recurved (see Heckert, 2004 for examples). MNA V10666 falls into neither category. While the tooth is moderately recurved it is also laterally compressed, especially compared to other teeth referred to *Crosbysaurus* in the literature. The posterior denticles bear fewer accessory denticles than any other *Crosbysaurus* teeth in the literature. The anterior denticles are much smaller, not compound, and are not found along the complete length of the anterior surface of the tooth.

It is tempting to think that these differences may be systematically significant. We refrain from using these differences to taxonomically segregate MNA V10666 from other *Crosbysaurus* specimens, however, for several reasons. The sample size from Utah is low (n=1) and individual variation within this taxon has not been quantified. In addition we lack any other body fossil

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remains from *Crosbysaurus* so it is unknown what role tooth position has in tooth morphology. Coupled with the taxonomic and systematic problems associated with *Revueltosaurus* (Hunt, 1989; Hunt and Lucas, 1994; Heckert, 2002; Parker et al., 2005; Heckert, 2005; Irmis et al., 2006; Heckert et al., 2012), a taxon whose relationship and taxonomy has been radically altered by the discovery of body fossils, we refrain from adding to the confusing plethora of tooth taxa known from the Late Triassic of North America.

Previous authors have suggested that *Crosbysaurus* is useful as a biostratigraphic index taxon of the St. Johnian division of the Adamanian LVF assemblage (late Carnian in age) (Heckert and Lucas, 2006). If these previous workers are correct MNA V10666 may provide an important lower limit on the age of the Chinle Formation at Comb Ridge, an area that has received little paleontological or stratigraphic work. Such correlations should be treated as highly tentative, however, pending further stratigraphic work at Comb Ridge by the authors and others. Considering the different morphology found in MNA V10666 and other specimens of *Crosbysaurus* it is possible that this taxon may not be as useful as an index fossil as originally suggested. This view is bolstered by the discovery of a single isolated tooth of *Reticulodus synergus* (MNA V10652) at a similar stratigraphic level north of The Hills Have Teeth locality by the first author. *R. synergus* has been regarded as an index taxon for the Norian-aged Revueltian LVF (Heckert and Lucas, 2006). While detailed stratigraphic work remains to be done the data available at this time suggest that MNA V10666 is Norian in age. The occurrence of two index taxa from different LVFs in the same stratigraphic range would reduce the biostratigraphic utility of those taxa. It is hoped that additional remains of both taxa will be recovered at Comb Ridge by future workers to provide additional data to test these conclusions.

CONCLUSIONS

The discovery of *Crosbysaurus* from the Chinle Formation of southeastern Utah extends the geographic range of this taxon northward by approximately 250 kilometers. *Crosbysaurus* was apparently a rare but widespread species during Chinle deposition times. The single tooth recovered, MNA V10666, bears unique morphological characteristics that separate it from other published specimens of *Crosbysaurus* as well as other contemporaneous herbivorous archosaurs such as *Revueltosaurus*. These characters may represent various tooth positions within the jaw, variation between individuals, or taxonomic differences. The sample size and preservation of known specimens of *Crosbysaurus* does not allow us to discriminate between these sources of variation at this time so we refrain from making any statements about what the primary cause is. The near co-occurrence of *Reticulodus synergus* and *Crosbysaurus* may have implications for the utility of these taxa as biostratigraphic index fossils. The Chinle Formation at Comb Ridge has been mapped as the Petrified Forest Member (Bennett, 1955). If further investigations support this then MNA V10666 represents the youngest occurrence of *Crosbysaurus* and extends its stratigraphic range into the Norian. It is hoped that future work by Mission Heights' field crews can help better clarify the stratigraphic and taxonomic relationships of this enigmatic archosaur.

Acknowledgements

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The authors would like to thank Dave and Janet Gillette at the Museum of Northern Arizona for their help with curation, cataloging, and guidance on this project, as well as Andrew Heckert for his helpful comments on the identification of MNA V10666 and providing materials to assist in the preparation of this manuscript. The authors would like to also thank ReBecca Hunt-Foster for helping with the permitting process, as well as Matthew Chesney and Patrick Brown for helping get Mission Heights Paleontology fieldwork started.

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