Diversity of raptor dinosaurs in southeastern North America revealed by the first definite record from North Carolina

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Abstract.

During the Cretaceous period, North America was divided into two landmasses, the eastern Appalachia and western Laramidia. Recent research on several sites scattered across the eastern margin of North America has allowed for the analysis of vertebrate faunas from the once obscured terrestrial fossil record of Appalachia, revealing the landmass harbored a distinctive fauna composed of mostly relict forms. One geological unit that has produced a comparatively extensive record of terrestrial vertebrates, including non-avian dinosaurs, is the Tar Heel Formation of North Carolina. Here, I report the first definitive occurrence of a dromaeosaurid from the Tar Heel Formation in the form of a tooth from a fairly large member of that group. This tooth, like others previously discovered from the southeastern portion of North America, compares favorably with those of saurornitholestine dromaeosaurids from the western United States and Canada. The North Carolina tooth differs in morphology and size from previously reported southeastern North American dromaeosaurid teeth, but is still assignable to a saurornitholestine dromaeosaurid, evincing that the diversity of carnivorous bird-like dinosaurs in the southeastern part of North America during the Late Cretaceous may have been rather low. The tooth, which is intermediate in size between those of smaller dromaeosaurids like

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Saurornitholestes and gigantic forms like *Dakotaraptor*, helps fill the gap between larger- and smaller-bodied dromaeosaurids from the Late Cretaceous.

Keywords: Appalachia; Dinosauria; Theropoda; Dromaeosauridae.

Introduction.

The bird-like dromaeosaurids, a group of dinosaurs considered important for their phylogenetic proximity to the base of Aves, have a comparatively poor fossil record in the Late Cretaceous of North America and elsewhere (Evans et al. 2013). Although only seven taxa, *Dromaeosaurus albertensis* (Matthew and Brown 1922), *Saurornitholestes langstoni* (Sues 1978), *Atrociraptor marshalli* (Currie & Varricchio 2004), *Acheroraptor temertyorum* (Evans et al., 2013), *Dakotaraptor steini* (DePalma et al. 2015), and *Boreonykus certekorum* (Bell & Currie 2015), have been described, and dromaeosaurid occurrences in the Late Cretaceous of western North America are primarily based on teeth (e.g., Currie et al. 1990; Bazsio 1997; Sankey 2001; Larson 2008; Longrich 2008; Sankey et al. 2002; Sankey 2008; Larson and Currie 2013; Williamson & Brusatte 2014). In southeastern North America, where the terrestrial fossil record of the Mesozoic Era is especially fragmentary, reports of this group have been limited to several tooth crowns, three distal tibiotarsal elements, and two pedal unguals from the US states of South Carolina, Alabama, Georgia, and Mississippi, all of which being isolated specimens (Kiernan and Schwimmer 2004; Ebersole and King 2011; Schwimmer et al. 2015).

These isolated finds of dromaeosaurids provide important information for understanding the biogeography (Lehman 1997; Sankey 2008; Gates et al. 2010, 2012; Sampson et al. 2013;

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Larson and Currie 2013; Williamson and Brusatte, 2014) and evolution of vertebrates near the end of the Mesozoic (e.g., Brusatte et al. 2012; Mitchell et al. 2012), a period important for the diversification of dromaeosaurids particularly (e.g., Turner et al. 2007; Longrich and Currie 2009; Turner et al. 2012; DePalma et al. 2015).

Several sites in the southeastern United States mainly producing microvertebrate remains are primarily responsible for the extensive research and reconstruction of Cretaceous terrestrial vertebrate faunas from that region that has taken place in the past 30 years, despite often being marine or coastal in depositional origin. These include Stokes Quarry in South Carolina, which has produced a dinosaur fauna from the middle Campanian Coachman Formation that includes the tyrannosauroid *Appalachiosaurus montgomeriensis*, a dromaeosaurid similar to *Saurornitholestes langstoni*, a possible second dromaeosaurid represented by teeth, indeterminate maniraptorans, and indeterminate ornithomimosaurs, hadrosauroids, and hadrosaurids (Schwimmer et al. 2015). At the Hannahatchee Creek site in Georgia, tyrannosauroid, ornithomimosaur, hadrosaurid, and dromaeosaurid remains have been reported (Schwimmer et al. 1993; Ebersole and King 2011). The Chronister site of Missouri has produced the teeth of tyrannosauroids and dromaeosaurids (Fix and Darrough 2004; Darrough et al. 2005).

The Phoebus Landing site of North Carolina has also produced an extensive dinosaur fauna from the middle Campanian Tar Heel Formation that is somewhat similar in composition to other ones from southeastern North America. Several hadrosauroids, including the massive taxon *Hypsibema crassicauda*, are present at the site, along with material comparable to the tyrannosaur *Dryptosaurus aquilunguis* and indeterminate ornithomimosaur hindlimb material (Miller 1967; Baird and Horner 1979).

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Another site in Sampson County, North Carolina has recently emerged due to the discovery of a possible leptoceratopsian there (Longrich 2016). The deposits at Clifton Farm are also from the Tar Heel Formation, possibly representing a terrestrial deposit. A single theropod dinosaur tooth, YPM VPPU.023197, was also retrieved from the locality by Gerard Case in July of 1980. This tooth preserves several features diagnostic to the Dromaeosauridae and is the largest dromaeosaurid crown known from southeastern North America, as its incorrect referral to Tyrannosauroidea by Longrich (2016) attests. This tooth is not only important for being the first record of a dromaeosaurid from North Carolina and thus extending the known range of this clade of bird-like dinosaurs in North America, but also because the crown is unlike previously reported ones from the American southeast in several aspects of its morphology. The distinctiveness of the North Carolina dromaeosaurid tooth suggests that at least two different dromaeosaurid genera lived in southeastern North American during the Campanian and that bird-like dinosaur faunas may have differed regionally on Appalachia as they may have on Laramidia (e.g., Gates et al. 2010, 2012; Sampson et al. 2013; Williamson and Brusatte 2014).

Methods.

Permits.

No permits were needed for this study.

Measurements.

Measurements of the North Carolina tooth were taken in accordance with the methods of Hendrickx et al. (2015a) using digital calipers.

Nomenclature.

I follow the recently proposed nomenclature of Hendrickx et al. (2015a) in this study.

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Geological Setting.

Clifton Farm, Giddensville, Sampson County, North Carolina, USA. This site preserved freshwater to estuary deposits from the Tar Heel Formation, a middle Campanian unit (Harris and Self-Trial 2006; Longrich 2016). The site preserves the remains of the large crocodylian *Deinosuchus rugosus* and a possible leptoceratopsian maxillary fragment (Longrich 2016). The Tar Heel Formation is the lowest unit of the Black Creek Group and represents deltaic environments near the site of collection of the tooth described herein (Sohl and Owens 1991; Harris and Self-Trial, 2006). Lithologically, the Tar Heel Formation in the Cape Fear river area is composed of interceding micaceous and clayey sands and carbonaceous clays (Owens 1989).

Systematic Paleontology.

Dinosauria Owen 1842

Theropoda Marsh 1881

Coelurosauria von Huene 1914

Dromaeosauridae Matthew and Brown 1922

Dromaeosauridae indet.

Material: YPM VPPU.021397, isolated theropod tooth crown (Fig. 1).

Remarks: Assigned to Dromaeosauridae based on the combination of (1) unconstricted base of crown, (2) distal carina concave, (3) apically oriented, peg-like distal denticles, and (4) distal denticles much larger than mesial denticles. The tooth compares unfavorably to the only other known ziphodont theropods from Appalachia, intermediate-grade tyrannosauroids, in that teeth from those taxa are much larger, do not have apically oriented distal denticles, and lack the

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pronounced size difference between mesial and distal denticles seen in the former (Carr et al. 2005; Brusatte et al. 2011; Schwimmer 2016).

Description: YPM VPPU.021397 is the isolated tooth of a dromaeosaurid theropod dinosaur that includes the entire crown and the apical-most portion of the root. Measurements of the tooth may be found in Table 1. This specimen is exceptionally well-preserved for a Cretaceous eastern North American terrestrial vertebrate fossil. Both the mesial and distal carinae are present and preserve un-eroded denticles. However, apicobasally-oriented cracking appears in the enamel layer along the majority of the tooth. The largest of these cracks runs parallel to the apical length of the tooth, beginning at the basal end of the mesial carinae and curving to its end within the middle of the crown apex. The enamel layer at the apex of the crown also appears flaked. This flaking may be due to damage from feeding consistent with spalled surfaces in other theropod teeth (e.g., Hendrickx et al. 2015b) or simply an artifact of abrasion from pebbles or other hard substances during deposition in a deltaic environment.

The tooth is classically theropod-like in possessing the mediolaterally-compressed condition (ziphodonty). YPM VPPU.021397 is strongly recurved as in other dromaeosaurid dinosaurs (Turner et al. 2012; Evans et al. 2013; Larson and Currie 2013; Williamson and Brusatte 2014). However, the tooth is less recurved than those present in the maxilla and dentary of *Atrociraptor*, *Bambiraptor*, or *Deinonychus* (Ostrom 1969; Burnham et al. 2000; Currie and Varricchio 2004). As in other dromaeosaurids, the tooth is distally concave, producing a “kinked” shape in labial and lingual views (Fig. 1A-B). A portion of the basal end of the tooth is not covered with enamel and not bordered by denticles mesiodistally, indicating it represents the apical-most portion of the root. The base of the tooth, as in other dromaeosaurids, is

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unconstricted. In basal view, the North Carolina tooth is slightly figure-8 shaped. However, this condition in YPM VPPU.021397 is not as pronounced as in *Deinonychus* and other dromaeosaurids (Fig. 1C, H; Ostrom 1969; Sues 1978; Burnham et al. 2000; Currie and Varricchio 2004; Turner et al. 2012; Larson and Currie 2013; Williamson and Brusatte 2014). In basal view, the thickness of the layer of enamel and dentine n the tooth are revealed (Fig. 1C).

The distal carina preserves a total of 55 denticles (Fig. 1A-B). All are squarish and slightly apically oriented (Fig. 1E), with large interdenticular sulci that project onto the crown separating each. As in other dromaeosaurid crowns, the distal denticles are largest midway up the tooth and decrease in mesiodistal length apically (e.g., Currie et al. 1990; Turner et al. 2012; Evans et al. 2013; Larson and Currie 2013). These denticles have a frequency of 4/mm basally and 3/mm apically and midway up the crown. The mesial denticles are much smaller than the distal ones and more mesiodistally compressed. These have a frequency of 4/mm apically and midway along the crown, as the basal-most are not present, either owing to taphonomic processes or their actual absence on the tooth.

The tooth is rather large and widened for a Late Cretaceous North American dromaeosaurid and is more similar in dimension to the crowns of larger dromaeosaurids like *Deinonychus* and *Dakotaraptor* (Ostrom 1969; DePalma et al. 2015) than to the many smaller forms that dominated the western Interior during this time (e.g., *Saurornitholestes, Bambiraptor*, *Atrociraptor*, *Acheroraptor*; Sues 1978; Burnham et al. 2000; Evans et al. 2013; Larson and Currie 2013). The tooth is also much larger than previously described eastern North American dromaeosaurid crowns, which are all ~5 mm in crown height (Kiernan and Schwimmer, 2004; Schwimmer et al. 2015).

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Discussion.

Kiernan and Schwimmer (2004) described the first dromaeosaurid tooth from the southeastern United States, which they noted shared several features with the western North American taxon *Saurornitholestes langstoni*. This tooth, which was recovered from the early Campanian Mooreville Chalk Formation of Alabama, is much smaller than YPM VPPU.021397, measuring 4.9 mm in crown height (Kiernan and Schwimmer 2004). Additionally, the Alabama tooth possesses higher distal and mesial denticle densities than YPM VPPU.021397 (7 v 3.5 (avg.) d/mm and 4 v 9 d/mm, respectively; Kiernan and Schwimmer 2004). The two teeth described by Schwimmer et al. (2015) from the Coachman Formation of South Carolina (overlapping in age with the Tar Heel Formation in the Cape Fear River area; Harris and Self-Trial 2006; Schwimmer et al. 2015) are also much smaller than YPM VPPU.021397. Like the Alabama tooth described by Kiernan and Schwimmer (2004), these South Carolina teeth possess higher mesial and distal denticle counts than YPM VPPU.021397 and have fewer denticles on the mesial and distal carinae overall than those present on the North Carolina specimen. All these morphological differences in these southeastern North American teeth have previously been reported among the dentition of individual dromaeosaurids (e.g., Smith et al. 2005; Turner et al. 2012). Three possibilities regarding the specific affinities of these southeastern North American dromaeosaurid teeth seem evident: (1), that all of these teeth represent different tooth positions in the jaw of the same dromaeosaurid taxon, (2) that these teeth represent different stages in the ontogeny of the same taxon, or that (3) the North Carolina tooth belongs to a previously unidentified morphotype of dromaeosaurid from southeastern North America. In any case, the fact that all of these teeth are rather similar to each other in curvature, distal and mesial denticle

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morphology (all possess peg-like distal denticles separated by large interdenticular sulci) evinces the low morphological diversity in bird-like dinosaurs from the Cretaceous of southeastern North America. The lack of diversity among tooth types in these southeastern North American specimens contrasts with the situation in the American southwest, where tooth assemblages with specimens belonging to two or more dromaeosaurids, troodontids, and several other morphotypes of coelurosaurian theropod are present (Sampson et al. 2013; Williamson and Brusatte 2014). Nevertheless, the situation in southeastern North America could easily occur due to preservation biases that reflect a lower diversity of carnivorous bird-like dinosaurs living along the coastline.

The North Carolina dromaeosaurid tooth described herein does, however, reflect size disparity among carnivorous bird-like dinosaurs in the Late Cretaceous of North America. The majority of Campanian North American dromaeosaurids have teeth much smaller than YPM VPPU.021397 (Sues 1978; Currie 1990; Burnham et al. 2000; Sankey et al. 2002; Currie and Varricchio 2004; Larson and Currie 2013; Williamson and Brusatte 2014). The North Carolina tooth compares best in size with crowns from *Deinonychus* out of other dromaeosaurid taxa known from North America (e.g., Ostrom 1969; Kirkland et al. 1993; Evans et al. 2013; DePalma et al. 2015), as only a handful of teeth assignable to saurornitholestine and dromaeosaurine dromaeosaurids from the Late Cretaceous western Interior overlap in size with the specimen described herein (suppl. info., Larson and Currie 2013). Several very large dromaeosaurids are known from the Late Cretaceous, including the Mongolian eudromaeosaur *Achillobator* and Argentinian unenlagiine *Austroraptor* (Perle et al. 1999; Novas et al. 2008). YPM VPPU.021397 thus represents a dromaeosaurid of intermediate size between the smallest

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(<100 cm) Late Cretaceous forms (e.g., Turner et al. 2007; Longrich and Currie 2009) and gigantic forms (Perle et al. 1999; Novas et al. 2008; DePalma et al. 2015).

Conclusions.

YPM VPPU.021397, the first definite occurrence of a dromaeosaurid in North Carolina, shares features with other southeastern North American dromaeosaurid teeth. However, the tooth described herein is much larger than previously described specimens, suggesting it represents a different tooth position, an ontogenically further progressed individual, or a previously unrecognized dromaeosaurid tooth morphotype. The tooth is important for helping to fill the gap between the larger (≥ 4 m) and smaller (≤ 2 m) dromaeosaurids of the Late Cretaceous, representing an animal similar in size to *Deinonychus* (Ostrom 1969). YPM VPPU.021397 is additionally important for revealing the comparatively obscure dinosaur faunas from the Cretaceous of eastern North America.

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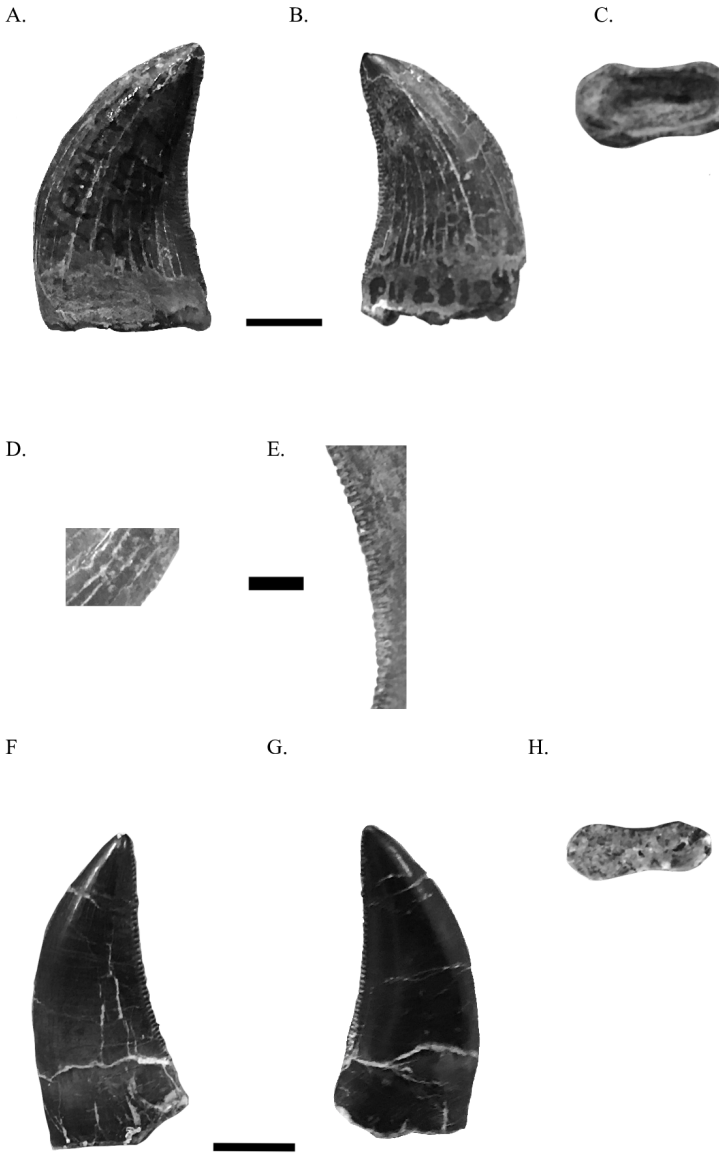

YPM VPPU.021397 in ?labial (A), ?lingual (B), and basal (C) views, with close-ups of the mesial (D) and distal (E) denticles. *Deinonychus* tooth in labial (F), lingual (G), and basal (H) views for comparison. Scale bar = 5 mm (A-C, F-H), 1 mm (D-E). Courtesy of the Division of Vertebrate Paleontology; YPM VPPU.21795, Peabody Museum of Natural History,Yale University, New Haven, Connecticut, USA; peabody.yale.edu.

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Table 1. Measurements of YPM VPPU.021397.

Dimension (after Hendrickx et al. 2015a)	Measurement (in mm)
CBL	11.5
CBW	5.1
CH	18
AL	20
CBR	0.443
CHR	1.565
MC	4
DC	3

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