The Carnivorous Dinosaurs

Edited by Kenneth Carpenter

Indiana University Press
Bloomington & Indianapolis

This book is a publication of
Indiana University Press
601 North Morton Street
Bloomington, IN 47404-3797 USA
http://iupress.indiana.edu

Telephone orders 800-842-6796
Fax orders 812-855-7931
Orders by e-mail iuporder@indiana.edu

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Manufactured in the United States of America

Library of Congress Cataloging-in-Publication Data

The carnivorous dinosaurs / edited by
Kenneth Carpenter.
p. cm. — (Life of the past)
Includes bibliographical references
(p.) and index.
ISBN 0-253-34539-1 (cloth : alk.
paper)
1. Saurischia—Juvenile literature.
I. Carpenter, Kenneth, date-
II. Series.
QE862.S3C27 2005
567.912—dc22

2004023225

1 2 3 4 5 10 09 08 07 06 05

7. Theropod Teeth from the Upper Cretaceous (Campanian-Maastrichtian), Big Bend National Park, Texas

Julia T. Sankey, Barbara R. Standhardt, and Judith A. Schiebout

Abstract

Big Bend National Park, Texas, has one of the southernmost terrestrial records for the Late Cretaceous in North America. Cretaceous theropod dinosaurs are not as well known from southern North America as from more northern areas. Theropod teeth were collected from microfossil sites from the Upper Cretaceous upper Aguja and lower Tornillo formations, spanning the late Campanian to late Maastrichtian (approximately 74–67 Ma). In addition to previously recognized taxa from Campanian sites, several teeth from Maastrichtian sites are unlike any previously described from Big Bend. These new morphotypes are referred to as *Saurornitholestes* n. sp.?. Theropods present in the Campanian and Maastrichtian of Big Bend include tyrannosaurids, *Saurornitholestes* cf. *S. langstoni*, *Saurornitholestes* n. sp.?, *Richardoestesia* cf. *R. gilmorei*, *R. isosceles*, and cf. *Paronychodon*. Additionally, possible bird teeth are tentatively identified in the assemblage. *Saurornitholestes* n. sp.? and cf. *Paronychodon* occur only in the Maastrichtian sites, suggesting that there were distinct Campanian and Maastrichtian theropod assemblages in Big Bend, as there were in northern areas. Absent from both the Campanian and Maastrichtian

assemblages in Big Bend are *Dromaeosaurus albertensis* and *Troodon formosus*, which are common in northern areas. Also, many taxa are represented by teeth of hatchlings or juveniles, demonstrating that the animals nested in this area.

Introduction

The first thorough study of theropod teeth (Currie et al. 1990) was based on collections from the Upper Cretaceous (upper Campanian) Judith River Group of Alberta and included detailed descriptions and illustrations of tooth and denticle morphology. This collection increased in size as a result of an extensive screenwashing program (Brinkman 1990; Peng et al. 2001), which allowed Baszio (1997a,b) to document the range of variation of theropod teeth and to discern important paleoecologic patterns during the Late Cretaceous. The collection was increased to over 1,700 teeth by additional screenwashing, and Sankey et al. (2002) described and measured the collection, quantifying the range of variation in both known taxa and new morphotypes. These new morphotypes, possibly representing new taxa, are particularly significant because they document higher theropod diversity in the assemblage than was previously recognized. Bird teeth were also described. Because the collection of theropod teeth from the Judith River Group is the largest and most thoroughly studied for the late Campanian, it is frequently used in comparisons with other contemporaneous faunas, such as the theropods from Big Bend National Park, Texas.

The theropods from Big Bend are important because they are some of the southernmost records from the Late Cretaceous of North America. Big Bend (Fig. 7.1) was within the southern biogeographic province (Lehman 1997), which was characterized by the *Normapolles* palynoflora, with a warm, dry, non-seasonal climate and open canopy woodlands. Differences between the southern and northern provinces (Wyoming and north) were primarily due to differences in temperature and rainfall (Lehman 1997).

Considerably less is known about the dinosaurs in the southern province compared to the northern province, partly because there is less outcrop area and there are fewer paleontologists working in the area (Lehman 1997). However, the lack of information is also due to there being fewer and less well preserved fossils. One factor involved in this taphonomic bias in Big Bend was that uplands were relatively distant, resulting in slower sedimentation rates and condensed stratigraphic and faunal records compared to those of northern areas. Increased aridity during the Late Cretaceous, due to climate change, retreat of the Western Interior Seaway, and uplift of the western mountains, occurred earlier in the Late Cretaceous in this area than in the north. For example, the dinosaur bone beds in the Aguja Formation (upper Campanian) of Big Bend probably formed during periodic droughts that were severe enough to cause marshes to dry up (Davies and Lehman 1989).

The first screenwashing program of Cretaceous microsites in Big

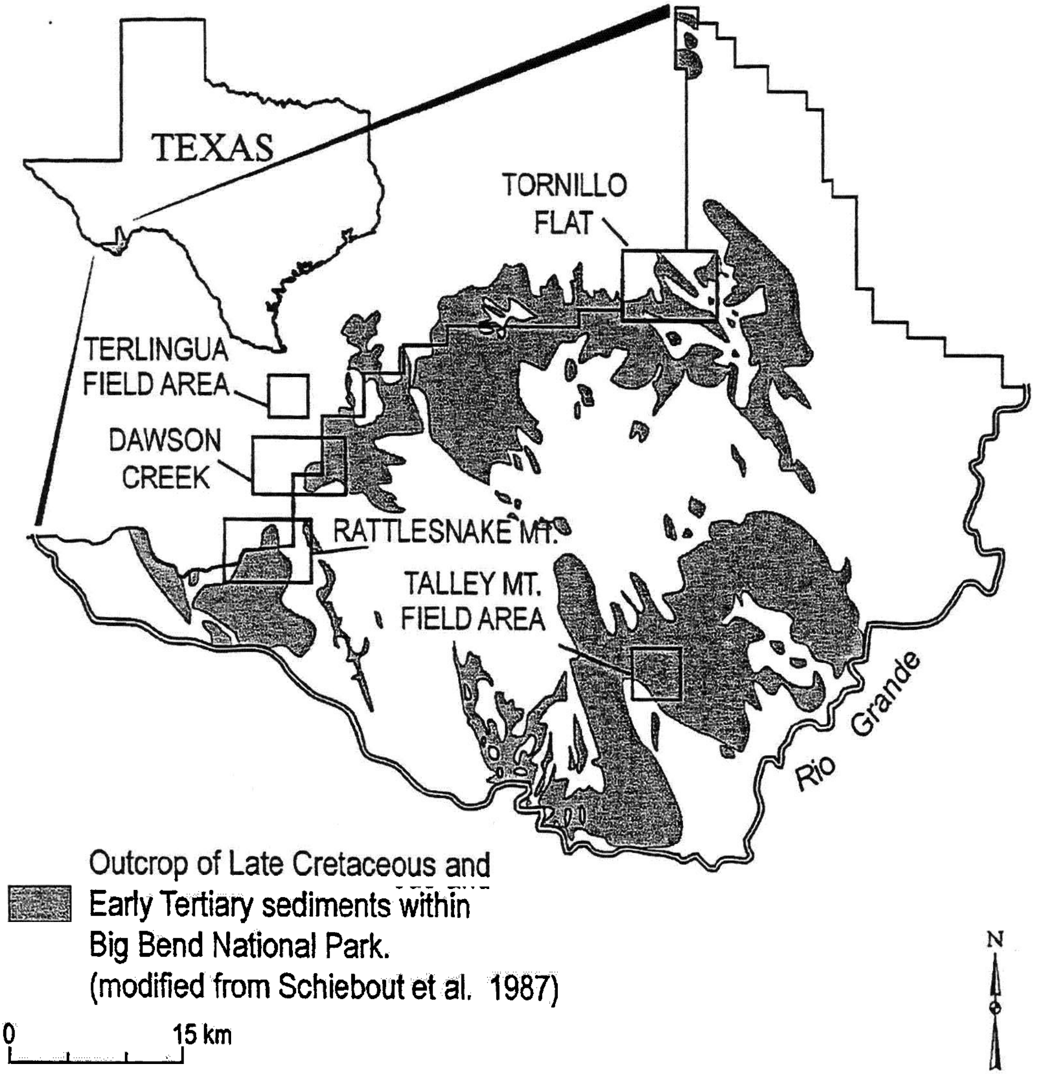

Figure 7.1. Map of Big Bend National Park, Texas.

Bend was developed by Judith Schiebout (Louisiana State University) and her students in the 1980s (Standhardt 1986) and continues today with Sankey (1998, 2001; Sankey and Gose 2001). These efforts have produced samples of dinosaur and other vertebrate small teeth and bones. Although the collection is considerably smaller than that from the Judith River Group because there are fewer productive microsites in Big Bend, it is important because it documents the theropods from this area. The goals of this research are to determine (1) what theropod taxa occurred in Big Bend; (2) whether they were different from northern theropods; (3) whether there were differences between the Campanian and Maastrichtian theropod assemblages; and (4) whether theropod diversity changed in Big Bend during the last 10 million years of the Cretaceous.

Maastrichtian theropods collected by Standhardt (1986) from microsites in the uppermost Aguja (lower Maastrichtian) and lower Tornillo (Maastrichtian) are included in this paper. Within this collection there are new morphotypes of *Saurornitholestes,* which may represent one or more new species.

Rowe et al. (1992) reported late Campanian theropods collected by screening the Terlingua microsite (upper Aguja). A few of the illustrated teeth were misidentified but were corrected by Sankey (2001). Additional late Campanian theropods (and other dinosaurs) were described by Sankey (2001) from screened Talley Mountain microsites (upper Aguja), including a new species of theropod, *Richardoestesia isosceles.* Recent collections of late Campanian theropods from newly discovered microsites at Rattlesnake Mountain (upper Aguja) are reported here, further documenting Big Bend theropod variation and diversity.

Stratigraphy

Aguja Formation. The Aguja Formation (upper Campanian to lower Maastrichtian; Fig. 7.2) contains coastal and floodplain sediments deposited during the final retreat of the Western Interior Seaway from Big Bend. The Aguja is a widespread, eastward-thinning unit of 135 to 285 m of paralic and marine sandstones interbedded with shale and lignite (Lehman 1985). The Terlingua Creek sandstone member represents the last marine transgression (Regression 8 of Kauffman 1977), and the overlying upper shale member represents the last pre-Laramide tectonic sedimentation in the area (Lehman 1991). In the lower part of the upper shale member are carbonaceous mudstones, thin beds of lignite, and large siderite ironstone concretions representing distributary channels, levees, crevasse splays, and poorly drained interdistributary marshes and bays. The upper part, with variegated mudstones and sandstones containing conglomeratic lags of paleo-caliche nodules, represents fluvial environments within a deltaic coastal plain and inland floodplain (Lehman 1985, 1991).

Magnetostratigraphy of the upper shale member of the Aguja Formation in the Talley Mountain area correlated the deposits to the base of Chron 32, or approximately 71–74 Ma (late Campanian–early Maastrichtian) (Sankey and Gose 2001). This correlation was constrained by the following evidence. First, the marine Terlingua Creek sandstone, which underlies the upper shale member, is middle Campanian in age (Lehman 1985; Rowe et al. 1992). Of particular importance is the presence within this unit of *Baculites maclearni* (Rowe et al. 1992), a zonal index fossil for the middle Campanian, with a duration of approximately 79.6 to 80.2 Ma (Obradovich 1993). Second, western-most outcrops of the lower portion of the upper shale member of the Aguja Formation are middle Campanian on the basis of mammals from Terlingua (Cifelli 1995; Rowe et al. 1992; Weil 1992, 1999). Third, mammals from the upper shale member of the Aguja in the Talley Mountain area include *Alphadon* cf. *A. halleyi* (LSU-6252), a cosmopolitan marsupial that is characteristic of Judithian (North American Land Mammal "Age") faunas (Lillegraven and McKenna

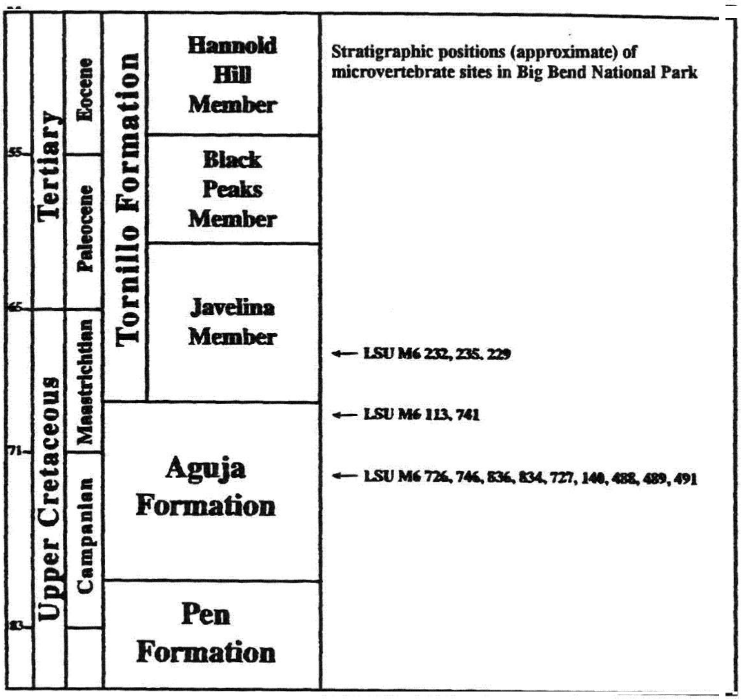

Figure 7.2. Stratigraphy of Aguja and Tornillo formations, with positions of microsites (modified from Schiebout et al. 1987; Standhardt 1986).

1986) and is also found from Terlingua (Rowe et al. 1992). The known range of the Judithian is approximately 5 million years, from ~75 to 78 Ma (Goodwin and Deino 1989) or ~74 to 79 Ma (Lillegraven and McKenna 1986). Fourth, the uppermost part of the upper shale member is lower Maastrichtian, on the basis of vertebrates, especially mammals, and limited magnetostratigraphy (Lehman 1985, 1989, 1990; Standhardt 1986).

Tornillo Formation. Overlying the Aguja is the Tornillo Formation, which is an Upper Cretaceous through lower Tertiary deposit (stratigraphic terminology follows Schiebout et al. 1987). The Tornillo consists of mudstones and sandstones and represents fluvial floodplain deposition. The mudstones often contain prominent color banding, indicating different paleosols. Fluctuations in water table levels were due to climatic changes, sea level changes, or both, with the black and very dark red beds indicating high water tables, and the red and gray beds, containing abundant calcium carbonate nodules, indicating lower water tables (concentrating calcium carbonate in the B soil horizons; Schiebout et al. 1987).

The K/T boundary is within the Javelina member of the Tornillo Formation. At the Dawson Creek section, the boundary has been bracketed between fossil sites and is within a 35-m span of floodplain deposits. Sediments are fluvial mudstones containing strong color banding due to paleosol development. However, no physical evidence for the K/T impact event has been found in these deposits (Standhardt 1986; Schiebout et al. 1987; Lehman 1989, 1990).

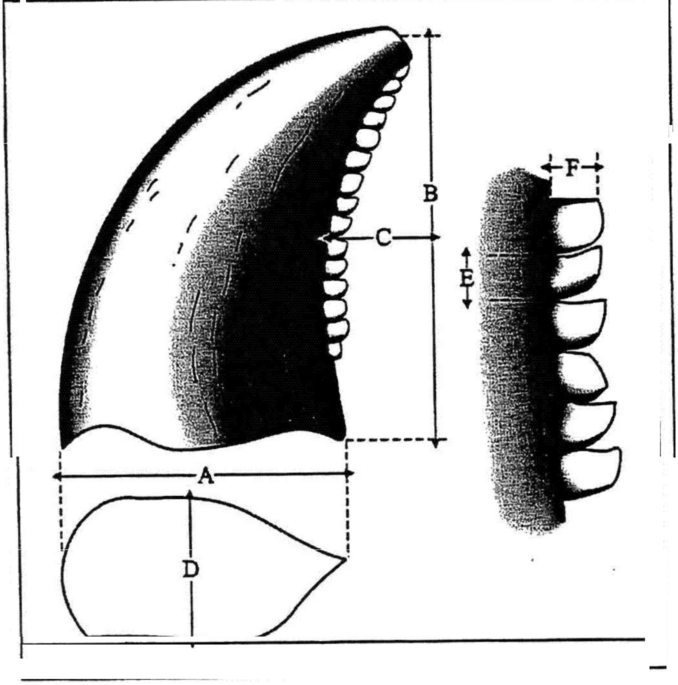

Figure 7.3. Measurements of teeth. (A) FABL, fore-aft basal length, not including denticles; (B) greatest height, from crown tip to base (not including root, if unshed tooth) and measured from posterior side; (C) curvature, the greatest distance from posterior carina (not including the denticles) to a perpendicular line from tooth tip to base; (D) cross-sectional thickness, the greatest lateral-lingual cross-sectional tooth thickness; (E) greatest denticle width; (F) greatest denticle height. Denticles/mm (of largest denticles present).

Materials and Methods

Fossil Sites. The specimens are from vertebrate microfossil sites from the Aguja and Tornillo formations. Fossils were collected by both surface collection and underwater screening techniques. Screened matrix was sorted with a dissecting microscope. Studies of the sedimentology, stratigraphy, palynology, and magnetostratigraphy provide a well-constrained stratigraphic framework for the sites (Lehman 1985; Standhardt 1986; Sankey 1998; Sankey and Gose 2001). All specimens are curated into the Louisiana State University Museum of Natural Science Vertebrate Paleontology Collections, where detailed locality information is on file.

When evaluating a morphologically distinct tooth, three alternatives were considered: that the tooth is (1) a variant along the tooth row; (2) a variant within the population but not expressed in each individual; (3) a distinct taxon. The third alternative is supported if the tooth morphotype has a distinct stratigraphic distribution. Although no new taxa are proposed in this study, a new and distinct morphotype of *Saurornitholestes* from a Maastrichtian microsite may represent a new species.

Measurements and Photographs. Locations for tooth measurements are illustrated in Figure 7.3. A microscope with an ocular micrometer was used by Sankey. Measurements are given in millimeters (mm) and are abbreviated as follows: FABL, fore-aft basal length; ht, height; curv, curvature; CST, cross-sectional thickness; CSS, cross-sectional shape; and dent/mm, denticles/mm. Measurement resolution is 0.5 mm for denticles/mm and 0.1 mm for denticle width and height. Measurements for specimens are available from Sankey.

TABLE 7.1

Tyrannosaurid Measurements (in mm)

Approximate measurements, due to broken tooth, represented by [ ]. If measurement not possible, represented by —.
—Denticle measurements were made on largest denticles present. Abbreviations: curvature (curv); fore-aft basal length (FABL); height (ht); width (wd); cross-sectional thickness (CST); cross-sectional shape (CSS); denticle (dent); denticles/mm (dent/mm); round (rd); fragment (frag); ant. (anterior); post. (posterior); flat (flattened).

LSUMG Spec. no.	LSUM. Local no.	Geo. fm.	Age	Curv	FABL	Ht	CST	CSS	Ant. dents present	Dents/mm post.	Dent.wd post.	Dent. ht. post.
6201	726	Aguja	late Camp	—	—	—	—	—	—	2	0.4	0.5
6209	726	Aguja	late Camp	—	—	—	—	—	yes	2.5	0.3	[0.2]
6218	726	Aguja	late Camp	no	8.3	[15]	5.8	rd/oval	yes	5	0.2	0.2
6219	726	Aguja	late Camp	—	—	—	—	—	—	—	—	—
6274	746	Aguja	late Camp	no	8.5	[20]	—	oval	yes	2.5	0.3	0.4
6227	746	Aguja	late Camp	—	—	—	—	—	—	2	0.5	0.4
6282	747	Aguja	late Camp	—	—	—	—	—	yes	—	—	—
6272	746	Aguja	late Camp	—	—	—	—	—	—	—	—	—
6262	746	Aguja	late Camp	—	[8.5]	15	5	oval	—	—	—	—
8199	836	Aguja	late Camp	no	[6.0]	—	5.5	rd	no	minute	—	—
8211	834	Aguja	late Camp	0.5	7	[10]	3.5	oval	yes	3.5	0.3	3
5914	727	Aguja	late Camp.	—	14	—	9	oval	yes	2	0.5	0.5
6042	727	Aguja	late Camp.	—	—	—	—	—	yes	4	0.2	—
6039	726	Aguja	late Camp.	—	—	—	—	—	—	—	—	—
6186	140	Aguja	late Camp	—	2.8	—	1.4	oval	yes	6	0.2	0.1
6236	489	Aguja	late Camp	—	3.5	—	2.6	rd	no	5.5	0.2	0.17
6239	489	Aguja	late Camp	—	4.8	—	[3.5]	oval/rd	no	5.5	0.2	0.3
5580	489	Aguja	late Camp	—	—	—		—	—	—	—	—
5483	488	Aguja	late Camp	—	8.7	—	5.7	oval/rd	yes	4	0.3	0.3
5987	741	Aguja	Camp/Maast	—	16	—	9	oval	yes	2.5	0.4	0.3

TABLE 7.1 *(cont.)*

Tyrannosaurid Measurements (in mm)

LSUMG Spec. no.	LSUM. Local no.	Geo. fm.	Age	Curv	FABL	Ht	CST	CSS	Ant. dents present	Dents/mm post.	Dent.wd post.	Dent. ht. post.
6024	741	Aguja	Camp/Maast	—	1.2	—	0.9	oval	no	7	0.2	0.2
5921	741	Aguja	Camp/Maast	—	—	—	—	—	—	—	—	—
5920	741	Aguja	Camp/Maast	—	[13]	—	[0.8]	oval	yes	2	0.4	0.4
5919	741	Aguja	Camp/Maast	—	12	[16]	7	oval	yes	2.5	0.4	0.3
6018	741	Aguja	Camp/Maast	—	[3.0]	—	1.9	oval	no	4	0.2	0.2
6015	741	Aguja	Camp/Maast	—	—	—	—	—	—	—	—	—
5922	741	Aguja	Camp/Maast	—	[14]	—	8	oval	yes	2.5	0.3	0.3
6017	741	Aguja	Camp/Maast	—	—	—	—	—	—	—	—	—
6020	741	Aguja	Camp/Maast	—	—	—	—	—	—	—	—	—
6016	741	Aguja	Camp/Maast	—	—	—	—	—	yes	4	0.3	0.2
6027	741	Aguja	Camp/Maast	—	—	—	—		—	—	—	
6036	741	Aguja	Camp/Maast	—	—	—	—	—	—	—	—	—
6023	741	Aguja	Camp/Maast	—	[2.0]	3	1.2	oval/rd	no	4.5	0.2	0.2
6021	741	Aguja	Camp/Maast	—	—	—	—	—	yes	5.5	0.2	0.2
6028	741	Aguja	Camp/Maast	—	—	—	—	—	—	—	—	—
6035	741	Aguja	Camp/Maast	—	—	—	—	—	—	—	—	—
6025	741	Aguja	Camp/Maast	—	—	—	—	—	—	—	—	—
6033	741	Aguja	Camp/Maast	—	—	—	—	—	yes	5	0.2	0.2
6031	741	Aguja	Camp/Maast	—	—	—	—	—	—	5	0.2	0.23
6029	741	Aguja	Camp/Maast	—	—	—	—	—	—	4	0.3	[0.2]
6032	741	Aguja	Camp/Maast	—	—	—	—	—	yes	6.5	0.1	[0.1]
5034	741	Aguja	Camp/Maast	—	—	—	—	—	—	—	—	—
6045	741	Aguja	Camp/Maast	—	—	—	—		yes	—	0.2	
6046	741	Aguja	Camp/Maast	—	—	—	—	—	—	—	—	—

TABLE 7.1 *(cont.)*

Tyrannosaurid Measurements (in mm)

LSUMG Spec. no.	LSUM. Local no.	Geo. fm.	Age	Curv	FABL	Ht	CST	CSS	Ant. dents present	Dents/mm post.	Dent.wd post.	Dent. ht. post.
5926	741	Aguja	Camp/Maast	—	—	—	—	—	—	—	—	—
6030	741	Aguja	Camp/Maast	—	—	—	—	—	—	—	—	—
1375	113	Aguja	Ea. Maast	[0.5]	3.6	[5.5]	3.2	rd	no	6.5	0.1	0.2
1313	113	Aguja	Ea. Maast.	—	—	—	—	—	yes	2.5	0.4	0.3
1312	113	Aguja	Ea. Maast.	—	—	—	—	—	—	—	—	—
5994	113	Aguja	Ea. Maast.	—		—	—	—	—	—	—	—
6003	113	Aguja	Ea. Maast.	—	—	—	—	—	—	—	—	—
6009	232	Tornillo	Maast	—	10.8	[20]	8	oval	yes	2.5	0.3	0.3
6011	232	Tornillo	Maast	none	15	[30]	19	oval	yes	2	0.4	—
6001	232	Tornillo	Maast	—	—	—	—	—	—	2	0.5	0.4
6012	232	Tornillo	Maast	—	—	—	—	—	—	2	0.5	[0.4]
6013	232	Tornillo	Maast	—	—	—	—	—	—	3.5	0.3	0.5
6008	232	Tornillo	Maast	—	—	—	—	—	—	—	—	—
6007	232	Tornillo	Maast	—	—	—	—	—	—	2.5	0.5	0.3
6006	232	Tornillo	Maast	—	14	—	8	oval	yes	3	0.3	—
5985	229	Tornillo	Maast	—	—	—	—	—	—	3	0.3	0.5
5957	229	Tornillo	Maast	—	—	—		—	—	4	0.3	0.3
5991	229	Tornillo	Maast	—	—	—	—	—	—	4	0.3	0.4
5992	229	Tornillo	Maast	—	—	—	—	—	—	—	—	—
5988	229	Tornillo	Maast	—	—	—	—	—	—	—	—	—
5944	229	Tornillo	Maast	—	—	—	—	—	—	—	—	—
1088	229	Tornillo	Maast	2	12	24	8	rd	yes	2.5	0.4	0.4
3059	235	Tornillo	Maast	—	—	—	—	—	—	—	—	—
1930	235	Tornillo	Maast	2	12	21	8	rd	yes	2.5	0.4	0.37
6005	235	Tornillo	Maast	—	—	—	—	—	—	2	0.4	0.3

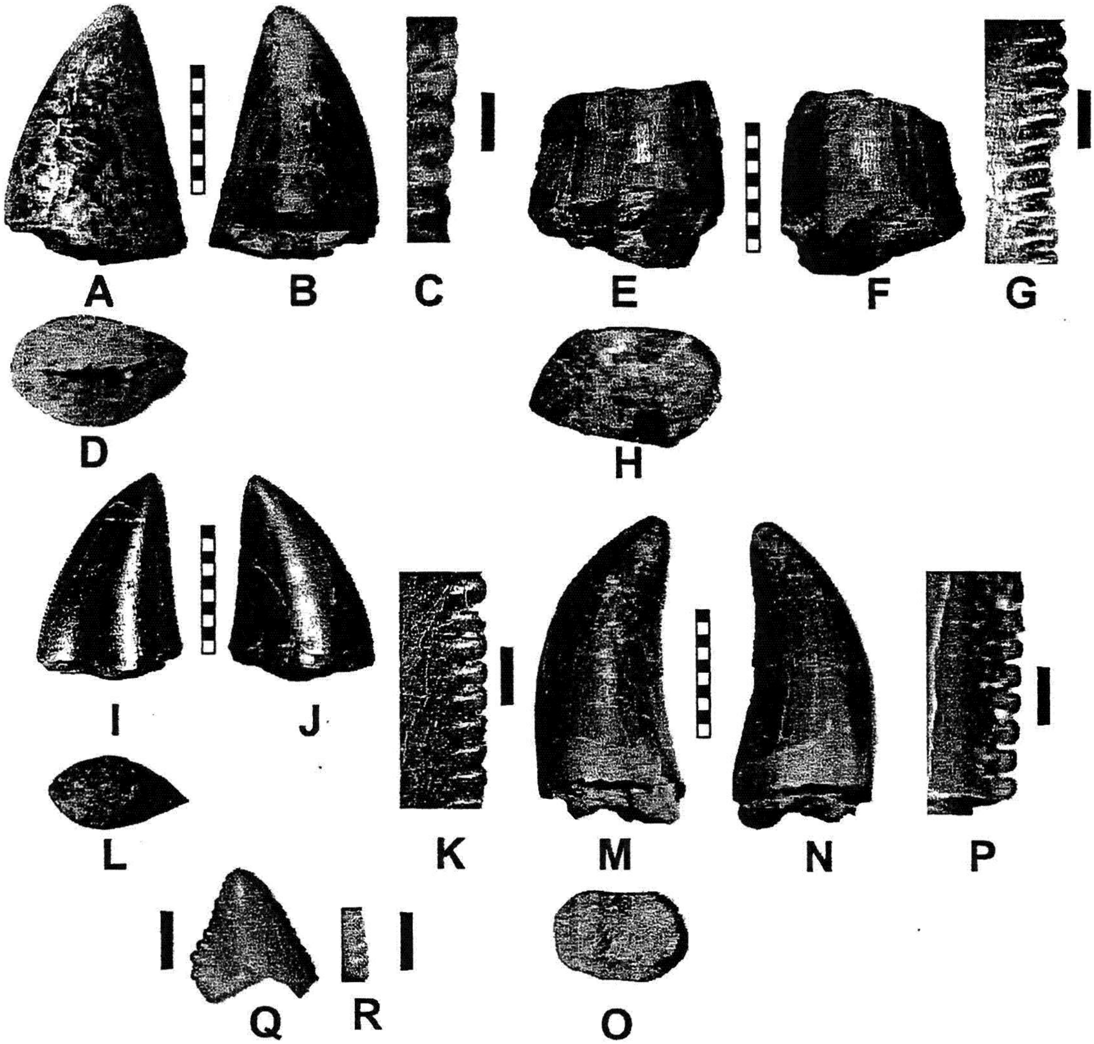

Figure 7.4. Tyrannosaurid teeth from the Aguja and Tornillo formations, Big Bend National Park, Texas, with views of lingual and labial sides, cross-section through base of tooth, and close-up of denticles. (A–D) LSU 727:5914; (E–H) LSU 741:5987; (I–L) LSU 741:5919; (M–O) LSU 229:1088; (Q–R) LSU 741:5926. Alternating black and white scale = 1 cm; solid black scale = 1 mm.

Institutional Abbreviations. LSU, Louisiana State University Museum of Natural Science, Baton Rouge; RTMP, Royal Tyrrell Museum of Palaeontology, Drumheller, Alberta; UALVP, University of Alberta, Lab for Vertebrate Paleontology, Edmonton; UCMP, University of California Museum of Paleontology.

Selected Systematic Paleontology

Order Saurischia Seeley 1888
Family Tyrannosauridae Osborn 1905
Tyrannosauridae Indeterminate
Table 7.1, Figure 7.4

Description. Teeth vary in size, ranging from large (Fig. 7.4A) to small (Fig. 7.4Q); and tooth shape cross-section varies from oval (Fig.

7.4L) to D-shaped (Fig. 7.4P). The degree of recurvature ranges from slightly recurved to none. Denticles are chisel-shaped with pointed tips. Denticles are present on both the anterior and the posterior carinae and are approximately equal in size on both carinae, although slightly larger on the posterior. Denticle size is approximately uniform from tooth base to tooth tip. Denticles/mm on posterior carinae range from 2 to 6/mm ($x = 3.6$, $n = 41$). Denticle width ranges from 0.2 to 0.5 mm ($x = 0.3$, $n = 42$). Denticle height ranges from 0.1 to 0.5 mm ($x = 0.3$, $n = 28$). (All denticle measurements were made on the largest denticles present on the posterior carinae; Fig. 7.3.)

Premaxillary teeth (LSU 489:6236, 6239; 113:1375) are round in cross-sectional shape, have little recurvature, and have no denticles on the anterior carinae.

Discussion. Tyrannosaurid teeth are more round in cross-sectional shape than other theropod teeth (Abler 1997). Denticles occur on both the anterior and the posterior carinae, denticles are approximately equivalent in size on both carinae, and there is less variation in denticle sizes between tooth base and tooth tip. Denticles are typically large and chisel-shaped, denticle width (labial-lingual) is greater than height (proximodistal), and denticles usually occur 3/mm (Currie et al. 1990). Tyrannosaurid denticles are typically the largest in labial-lingual width and have the largest and deepest interdenticle spaces of any theropod (Sankey et al. 2002). Abler (1997) and Baszio (1997b) discuss tyrannosaurid teeth in more detail.

Juvenile tyrannosaurid teeth (including fragments) are often found with small theropod teeth in upper Cretaceous vertebrate microfossil sites (Currie et al. 1990). For example, in one Big Bend microfossil site from Rattlesnake Mountain (uppermost Aguja; LSU-741; Figs. 7.1 and 7.4), juvenile tyrannosaurid teeth are the most abundant dinosaur specimens present. However, in other Big Bend microsites, tyrannosaurid teeth (juvenile and adult) are rare. For example, only one specimen was found out of 3,347 specimens from the Talley Mountain microsites (Sankey 2001). The Talley Mountain sites are from more coastal environments, and the Rattlesnake Mountain microsite is from a more inland environment, suggesting that tyrannosaurids (both juvenile and adult) lived in more inland areas in Big Bend. Different tyrannosaurids occurred in the Campanian and Maastrichtian. However, because distinguishing tyrannosaurid taxa with teeth is difficult, no differences could be determined between the Big Bend Campanian and Maastrichtian tyrannosaurids.

Family Dromaeosauridae Mathew and Brown 1922

Genus *Saurornitholestes* Sues 1978

Saurornitholestes cf. *S. langstoni* Sues 1978

Table 7.2, Figure 7.5

Description. Teeth are small, recurved, and flattened (labial-lingually). Denticles are slender and pointed.

Referred Specimens. LSU 726:5923, 5924, 5928, 6204; 741:5927, 5936, 5930, 5935, 5932, 5931, 5929; 796:6270, 6280; 140:6139,

TABLE 7.2

Saurornitholestes spp. Measurements (in mm)

Approximate measurements, due to broken tooth, represented by [ ]. If measurement not possible, represented by —. Denticle measurements were made on largest denticles present. Abbreviations: curvature (curv.); fore-aft basal length (FABL); height (ht); cross-sectional thickness (CST); cross-sectional shape (CSS); denticles/mm (dent/mm); rd (round); dent (denticles); ht (height); wd (width); frag (fragment); ant. (anterior); post. (posterior); flat (flattened).

LSUMG Spec. No.	LSUMG Local. No	Geo. Fm.	Age	Curv	FABL	HT	CST	CSS	Ant. dents present	Dents/mm post.	Dent. wd. post.	Dent. ht. post.
5923	726	Aguja	late Camp	0.4	4.0	5.3	2.0	oval	minute	4.5	0.2	0.3
6204	726	Aguja	late Camp	0.5	3.5	6	—	oval	minute	5	0.2	0.2
6270	746	Aguja	late Camp	—	4	—	1.8	oval	minute	6.5	0.1	0.1
6281	746	Aguja	late Camp	0.5	4.8	7.2	2.5	oval/rd	minute	6.5	0.2	0.2
6280	746	Aguja	late Camp	[0.5]	4	[7.5]	—	oval	minute	4	0.3	0.2
5924	726	Aguja	late Camp	0.4	4.0	—	—	oval	?	4.5	0.2	0.3
5928	726	Aguja	late Camp	[0.5]	[3.2]	—	—	oval	no	4.5	0.2	0.3
6139	140	Aguja	late Camp	0.2	3.7	[5.2]	1.6	oval	minute	5	0.2	worn
6185	140	Aguja	late Camp	—	3.3	—	1.5	oval	no	5	0.2	0.2
6183	140	Aguja	late Camp	—	—	—	—	—	—	—	—	
6132	140	Aguja	late Camp	—	—	—	—	—	—	—	—	—
6184	140	Aguja	late Camp	—	—	—	—	—	yes	—	0.1	—
6229	488	Aguja	late Camp	—	—	—	—	—	—	5	0.2	0.3
5659	489	Aguja	late Camp	[0.3]	2.3	2.8	1.4	oval	no	5	0.2	0.3
6234	489	Aguja	late Camp	—	—	—	—	—	yes	7	0.1	0.1
5950	491	Aguja	late Camp	—	2	[2.2]	1.1	oval	no	6	0.1	0.2
5980	491	Aguja	late Camp	—	—	—	—	—	—	—	—	—
5927	741	Aguja	Camp/Maas	—	—	—	—	—	?	4.5	0.2	0.2
5936	741	Aguja	Camp/Maas	—	—	—	—	—	?	6	0.1	0.2
5930	741	Aguja	Camp/Maas	—	3	—	1.3	oval	?	—	—	—

TABLE 7.2 *(cont.)*

Saurornitholestes spp. Measurements (in mm)

LSUMG Spec. No.	LSUMG Local. No	Geo. Fm.	Age	Curv	FABL	HT	CST	CSS	Ant. dents present	Dents/mm post.	Dent. wd. post.	Dent. ht. post.
5935	741	Aguja	Camp/Maas	—	—	—	1.5	oval	no	[5]	0.2	0.3
5932	741	Aguja	Camp/Maas	—	—	—	—	oval	no	4	0.2	0.3
5931	741	Aguja	Camp/Maas	—	[2.5]	—	1.3	oval	—	6	0.1	0.2
5929	741	Aguja	Camp/Maas	—	[3.8]	—	1.8	oval	—	4	0.2	0.3
5938	741	Aguja	Camp/Maas	—	2	—	0.8	oval	yes	7	0.1	0.1
5937	741	Aguja	Camp/Maas	—	[2.5]	—	1	oval	—	5	0.1	0.1
5109	113	Aguja	Ea. Maast.	0.2	2.8	[4.0]	1.2	oval	—	6	0.2	0.2
5940	113	Aguja	Ea. Maast.	—	—	—	—	—	—	—	0.2	0.2
1355	113	Aguja	Ea. Maast.	—	—	—	—	—	—	—	0.2	0.2
5942	113	Aguja	Ea. Maast.	—	—	—	—	—	—	—	0.1	0.2
1309	113	Aguja	Ea. Maast.	[0.2]	1.8	[2.2]	0.8	oval	no	7	0.2	worn
1307	113	Aguja	Ea. Maast.	0.5	4	6.2	1.8	oval	minute	9	0.2	worn
5156	113	Aguja	Ea. Maast.	—	[2.5]	[4.0]	—	—	yes	5	0.2	0.2
1308	113	Aguja	Ea. Maast.	0.5	4	[5.5]	1.9	oval	no	5	0.2	0.2
5943	113	Aguja	Ea. Maast.	—	—	—	1	oval, v. flattened	no	6	0.2	0.2
5953	229	Tornillo	Maast.	—	3.3	[4.0]	—	oval	no	5	0.2	0.3
5963	229	Tornillo	Maast.	0.5	3.6	4.5	1.8	oval	minute	4.5	0.2	0.3
1089	229	Tornillo	Maast.	0.3	4.8	7.5	—	—	?	5	0.2	0.3
3128	229	Tornillo	Maast.	0.4	[4.0]	[6.0]	1.7	oval	yes	5	0.2	0.2
5987	229	Tornillo	Maast.	—	[3.5]	—	—	oval	minute	4	0.2	0.2
3069	235	Tornillo	Maast.	—	—	—	—	oval	yes	—	—	—
1931	235	Tornillo	Maast.	0.5	3	3.5	1.3	oval	?	7	0.1	0.1
6000	232	Tornillo	Maast.	—	3.3	—	1.8	oval/round	no	6	0.1	0.2

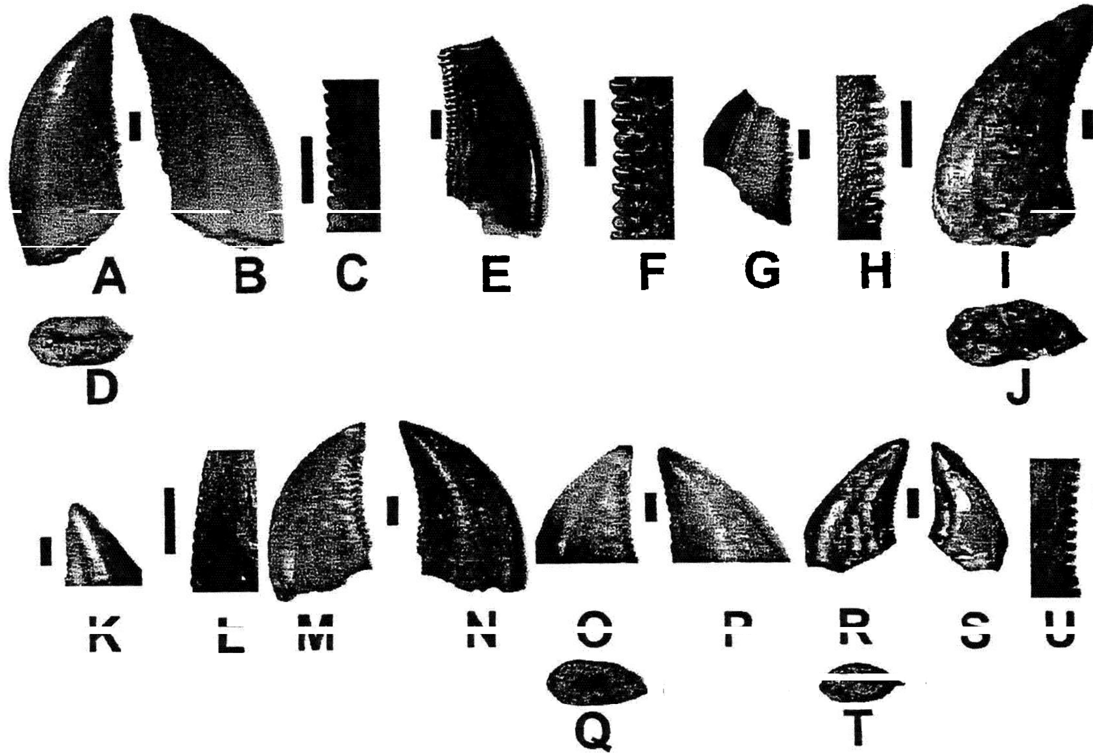

Figure 7.5. Saurornitholestes *teeth from the Aguja and Tornillo formations, Big Bend National Park, Texas, with views of lingual and labial sides, cross-section through base of tooth, and close-up of denticles.* Saurornitholestes *cf.* S. langstoni: *(A–D) LSU 726:5923; (E–F) LSU 726:5924; (G–H) LSU 741:5927; (I–L) LSU 113:1307.* Saurornitholestes *n. spA (M–Q) LSU 229:3128.* Saurornitholestes *n. sp. B (R–U) LSU 235:1931. Scale = 1 mm.*

6185; 489:5659; 491:5950; 488:6229; 229:5953, 5963, 1089; 113: 1308, 5943.

Description. Specimen LSU 726:5923 (Fig. 7.5A–D) is a typical example of this group. The tooth is small, recurved, sharply pointed, laterally compressed (labial-lingually), and oval in cross-sectional shape. Denticles on the anterior carinae, if present, are minute. Denticles on the posterior carinae are higher than they are wide, are sharply pointed toward the tip of the tooth, and vary in size from the tooth base to tooth tip. There are deep, narrow interdenticle spaces. The distinctive characteristics are (1) tooth recurved and flattened (labial-lingually); (2) absent or minute denticles on anterior carinae; and (3) long and pointed denticles on posterior carinae.

Denticles/mm on the posterior carinae range from 4 to 6/mm (x = 5.2, n = 24). Denticle width ranges from 0.1 to 0.2 mm (x = 0.2, n = 24). Denticle height ranges from 0.2 to 0.3 mm (x = 0.2, n = 24).

Discussion. These teeth are similar in both tooth and denticle shape and size to those identified and described as *Saurornitholestes* cf. *S. langstoni* from the Judith River Group of Alberta (Currie et al. 1990; Baszio 1997b; Sankey et al. 2002). In particular, these teeth closely match the specimen that is illustrated in Sankey et al. 2002 (figs. 4.14–4.17) and referred to Morphotype D (Sankey et al. 2002, Appendix 1.3) except that in the Big Bend specimens, denticles on the anterior carinae are either absent or minute. These teeth also closely resemble specimens illustrated in Currie et al. 1990 (fig. 8.2T–W) and in Baszio 1997b (plate I, 19–22, Dinosaur Park Group). The measurements of these samples are similar to measurements from this sample (Table 7.2). Sankey et al. (2002) measured ninety-nine *Saurornitholestes* cf. *S. langstoni* teeth, which had an average denticle height of 0.23 mm and an average denticle width of 0.18 mm. Also, Sankey et al. (2002) reported a wide range of variation in denticle size within the large sample of teeth studied, reflecting the presence of two or three distinct morphotypes in the sample. Most specimens are from sites within the upper Aguja Formation (upper Campanian to Campanian-Maastrichtian). However, three specimens (LSU 5953, 5963, 1089) are also from the lower Tornillo Formation (Maastrichtian). Additional specimens from these sites will test this pattern of relative abundance.

cf. *Saurornitholestes* n. sp.? A

Referred Specimens. 113:1307, 5156, 5109; 229:5987, 3128; 746: 6281.

Description. Specimen LSU 229:3128 (Fig. 7.5N–R) is a typical example of this morphotype. The tooth is small, recurved, flattened (labial-lingually), and oval in cross-sectional shape. Denticles on anterior carinae are present, but they are small, considerably smaller than posterior denticles. Denticles on posterior carinae are higher than they are wide and are slightly pointed. Denticles extend along the length of the carinae and are slightly smaller at the tooth tip. These teeth are similar to those of *S.* cf. *S. langstoni*, except in having anterior denticles and less-pointed posterior denticles. Denticles/mm on posterior carinae range from 4 to 9/mm ($x = 5.8$, $n = 5$). Denticle width ranges from 0.17 to 0.23 mm ($x = 0.79$, $n = 5$). Denticle height ranges from 0.17 to 0.23 mm ($x = 0.2$, $n = 5$).

Discussion. The presence of denticles on the anterior carinae is not size dependant, because both LSU 3128 and 5923 (*S.* cf. *S. langstoni*) are similar in size to teeth referred to cf. *S.* n. sp.? As discussed for *S.* cf. *S. langstoni* teeth, these teeth are also similar to those identified as *Saurornitholestes* cf. *S. langstoni* (Currie et al. 1990; Baszio 1997b; Sankey et al. 2002). They most closely match specimens illustrated in Baszio 1997b (plate II, 23–26, Horseshoe Canyon Formation). These teeth have been found only in Maastrichtian sites, and only from Big Bend. LSU site 113 is within the uppermost Aguja (lower Maastrichtian), and LSU site 229 is in the lower Tornillo (Maastrichtian; Standhardt 1986). Additional specimens of this morphotype would confirm this as a distinct taxon, especially if its stratigraphic distribution is restricted to Maastrichtian.

cf. *Saurornitholestes* n. sp.? B

Referred Specimen. 235:1931.

Description. Specimen LSU 1931 (Fig. 7.5S–U) is small, flattened (labial-lingually), oval in cross-sectional shape, and strongly recurved. Posterior denticles are unique. Denticle tips are not pointed, but are rounded in outline (the tooth is not worn). Interdenticle spaces are present. Anterior denticles are also present. Although the anterior carinae are missing, holes for denticles are present at the tooth base. Posterior denticles occur 7/mm and are 0.13 mm wide and 0.13 mm high (i.e., equally wide as they are high).

Discussion. LSU 1931 is unique in the following characteristics: (1) extremely recurved; (2) denticles present on both the anterior and posterior carinae; (3) denticles are small, approximately uniform in size from base to tip of tooth, and not pointed. The tooth is unlike any theropod tooth examined in the Tyrrell's or UCMP's collections. In tooth shape, the specimen resembles *Saurornitholestes* cf. *S. langstoni*, such as in Baszio 1997b (plate II, 28–Scollard Formation). However, in denticle shape and size, it resembles *Richardoestesia gilmorei* (Currie et al. 1990; Baszio 1997b; Sankey et al. 2002). The specimen is from a site (LSU 235) in the lower Tornillo Formation and is Maastrichtian in age. More specimens of this morphotype are needed to clarify whether this morphotype is restricted to the Maastrichtian in Big Bend.

cf. *Saurornitholestes* n. sp.? C

Referred Specimen. 232:6000.

Description. Specimen LSU 6000 is small, flattened (labial-lingually), and recurved. Because the cross-sectional shape is a rounded oval and because there are no denticles on the anterior carinae, this may be a premaxillary tooth, as discussed for *Saurornitholestes* in Sankey et al. 2002. Posterior denticles are long and slender. Denticles are 6/mm and are 0.13 mm wide and 0.2 mm high. Denticle tips are not pointed, but are rounded in outline. Distinct interdenticle spaces are present.

Discussion. Specimen LSU 6000 is a probable premaxillary tooth. It does not closely match any theropod teeth examined from the Judith River Group (Sankey et al. 2002). It is similar to *Dromaeosaurus* in the Scollard and Lance formations (Baszio 1997b, plates I, 9, and 13). This specimen is from a site, LSU-232, within the lower Tornillo Formation and is Maastrichtian in age.

Infraorder Maniraptora Gauthier 1986

Family Unknown

Genus *Richardoestesia* Currie, Rigby, and Sloan 1990

Richardoestesia isosceles Sankey 2001

Table 7.3

Referred Specimens. See Table 7.3.

Description. Teeth are small, with no or little recurvature, and are oval in cross-sectional shape. Denticles are present on both the anterior and the posterior carinae. Posterior denticles are minute. They occur 8–12/mm and are 0.1 mm wide and 0.1 mm high (i.e., equally high as they are wide). Denticles are not pointed.

Diagnosis. Because the holotype for this species is from Big Bend (Aguja; late Campanian; Sankey 2001) and the species was further

TABLE 7.3.

Richardoestesia Measurements (in mm)

Approximate measurements, due to broken tooth, represented by [ ]. If measurement not possible, represented by —. Denticle measurements were made on largest denticles present. Abbreviations: curvature (curv.); fore-aft basal length (FABL); height (ht); cross-sectional thickness (CST); cross-sectional shape (CSS); denticles/mm (dent/mm); rd (round); dent (denticles); ht (height); wd (width); frag (fragment); ant. (anterior); post. (posterior); flat (flattened).

LSUMG Spec. No.	LSUM. Local No.	Geo. Fm.	Age	Curv	FABL	Ht	CST	CSS	Ant. dents present	Dents/mm post.	Dent.wd post.	Dent. ht. post.
6140	140	Aguja	late Camp	—	2.2	—	1	oval	yes	minute	—	—
6237	489	Aguja	late Camp	—	2	[2.5]	0.9	oval	—	10	0.1	0.1
6238	489	Aguja	late Camp	straight	—	—	—	—	yes	7.5	0.1	0.1
6235	489	Aguja	late Camp	straight	1.7	[3.0]	0.7	oval	yes	11	0.1	0.1
6233	489	Aguja	late Camp	straight	—	—	—	round	yes	8	0.1	0.1
6264	492	Aguja	late Camp	straight	—	—	—	—	—	4?	0.3	0.2
6050	489	Aguja	late Camp	straight	1.7	[3.5]	1	oval	yes	10	0.1	0.1
6051	140	Aguja	late Camp	—	—	—	—	—	yes	9	0.1	0.1
5933	741	Aguja	Camp/Maas	—	[1.8]	[2.3]	0.9	oval	no	9	0.1	0.1
5934	741	Aguja	Camp/Maas	—	—	—	1	oval	?	8	0.1	0.1
5939	113	Aguja	Ea. Maast.	straight	[2.0]	[4.0]	1	oval	yes	12	0.1	0.1

described from specimens from the Judith River Group, Alberta (Sankey et al. 2002), descriptions from those papers are included here.

"Teeth straight; narrow; shaped like an isosceles triangle in lateral view (as mentioned for *Richardoestesia* sp. in Currie et al. 1990 and in Baszio 1997b). Shape of tooth in basal cross-section is labiolingually flattened oval. Denticles minute (0.1 mm in height and in anteroposterior width); square; uniformly-sized from base to tip of tooth; extend length of carinae. Anterior denticles, if present, often considerably smaller than posterior denticles. Interdenticle spaces usually minute and barely visible; denticles closely spaced. Denticle tips straight or faintly rounded, but not pointed. 7–11 denticles/mm" (Sankey 2001, p. 213).

Discussion. Sankey (2001) listed eight specimens from the Talley Mountain microsites (See Table 7.3). Three additional fragmentary specimens are reported here, all from the uppermost Aguja (Campanian-Maastrichtian). One fragmentary specimen of *R. gilmorei* was reported from Big Bend in Sankey 2001. However, no additional specimens have been recovered.

Straight teeth of *Richardoestesia* from the Judith River Group of Alberta were first recognized as a taxon distinct from *R. gilmorei* by Currie et al. (1990) and were referred to as *Richardoestesia* sp. Additional specimens from this area were described by Baszio (1997b) and Peng (1997; Peng et al. 2001). Baszio (1997a) made the important observation that teeth from *R. gilmorei* and *Richardoestesia* sp. have different relative abundance patterns in the Late Cretaceous of Alberta, reflecting their different paleoecologies and further supporting the idea that they represent distinct taxa. Sankey (2001) formally named *Richardoestesia* sp. on the basis of specimens from Big Bend. Sankey et al. (2002) described and measured further specimens from the Judith River Group, documenting qualitative and quantitative differences from *R. gilmorei*. *R. isosceles* is included in the genus *Richardoestesia* because of the presence of small denticles. Differences include the following: in *R. gilmorei,* teeth are usually shorter and more recurved, denticles are pointed, and small interdenticle spaces are present; whereas in *R. isosceles,* denticles are not pointed, and denticles are present on both anterior and posterior edges (Sankey et al. 2002).

Family Unknown

Genus *Paronychodon* Cope 1876

Paronychodon cf. *P. lacustris* Cope 1876

Referred Specimens. LSU 113:1310, 5107, 1311, 5993, 5996.

Description. Teeth are small, slightly recurved, flattened (labial-lingually), with one flattened side, and with distinct longitudinal ridges on both sides of tooth. No denticles are present on the anterior carinae. On the posterior carinae, denticles are absent, except in one specimen (LSU 5939) where they are minute.

Discussion. Teeth closely match specimens referred to *P. lacustris* from the Judith River Group, Alberta, in Sankey et al. 2002. Teeth from this poorly understood taxon were described, illustrated, and mea-

TABLE 7.4.

***Paronychodon* Measurements (in mm)**

Approximate measurements, due to broken tooth, represented by [ ]. If measurement not possible, represented by —. Denticle measurements were made on largest denticles present. Abbreviations: curvature (curv.); fore-aft basal length (FABL); height (Ht); cross-sectional thickness (CST); cross-sectional shape (CSS); denticles/mm (dent/mm); rd (round); dent (denticles); ht (height); wd (width); frag (fragment); ant. (anterior); post. (posterior); flat (flattened).

LSUMG Spec. No.	LSUM. Local No.	Geo. Fm.	Age	Curv	FABL	Ht	CST	CSS	Ant. dents present	Dents/mm post.
1310	113	Aguja	Ea. Maast.	[0.2]	3.6	[5.5]	2	oval, 1 flat side	no	none
5107	113	Aguja	Ea. Maast.	[0.2]	1.6	[3.0]	1.1	round, 1 flat side	no	none
1311	113	Aguja	Ea. Maast.	—	2.2	—	1.3	flat side	no	none
5993	113	Aguja	Ea. Maast.	—	1.7	[2.5]	0.9	oval	no	none
5996	113	Agua	Ea. Maast.	—	—	—	—	1 flat side	—	—

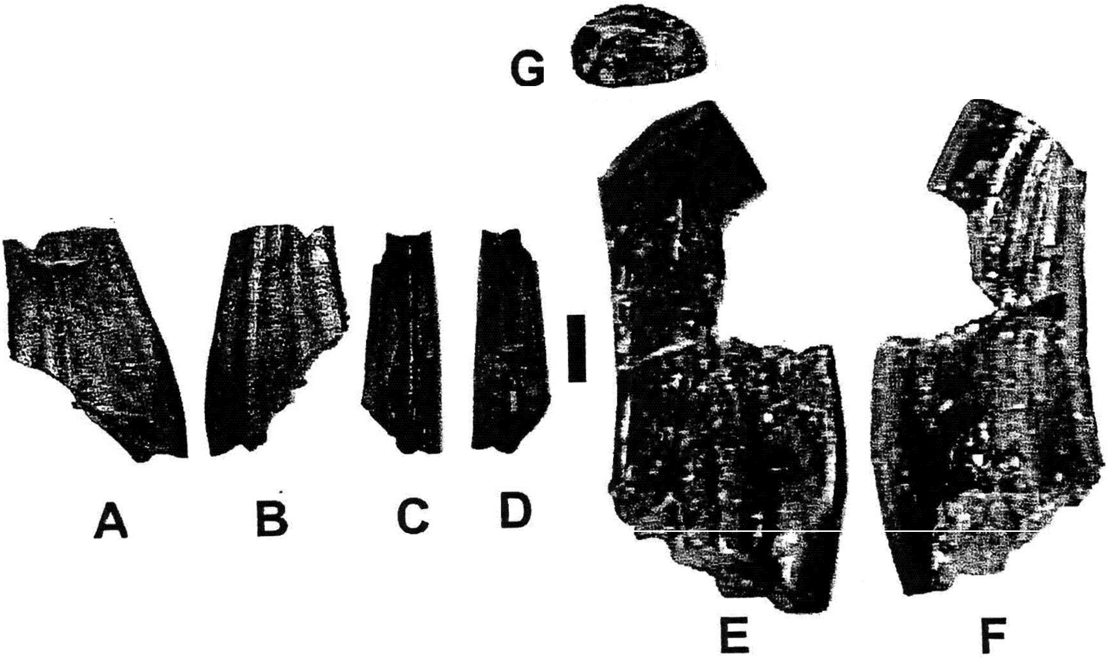

Figure 7.6. Paronychodon *teeth from the Aguja and Tornillo formations, Big Bend National Park, Texas, with views of lingual and labial sides, cross-section through base of tooth, and close-up of denticles. (A–D) LSU 113:5939, (E–G) LSU 113–1310. Scale = 1 mm.*

sured, and the features that distinguish them from similar taxa were pointed out (Sankey et al. 2002). Teeth have one flattened surface, numerous and well-developed longitudinal ridges, and no denticles. Two morphotypes were recognized. Morphotype A is larger, straighter, and not constricted at the base. Morphotype B is smaller and more recurved and has a distinct constriction below the crown. Although the Big Bend specimens are fragmentary, they more closely resemble Morphotype A because they are straight or only slightly recurved and have no constriction below the crown.

All Big Bend specimens reported here are from one lower Maastrichtian site (LSU 113) from the uppermost Aguja in the Dawson Creek area. They most closely resemble *Paronychodon lacustris* Morphotype B (Sankey et al. 2002, figs. 5.25–5.27). *Paronychodon* teeth are uncommon in most Late Cretaceous assemblages. However, they are more common in Maastrichtian sites, and it is important to note that this same pattern occurs in Big Bend.

cf. Class Aves Linnaeus, 1758

Table 7.5

Referred Specimens. LSU 113:5995; 232:5999.

Description. Teeth are small, round to oval in cross-sectional shape, and with little recurvature. No denticles are present on either the posterior or the anterior carinae.

Discussion. Teeth resemble those referred to birds in Sankey et al. 2002 in the following characteristics: teeth are small, round to oval in cross-sectional shape, slightly laterally compressed, straight, indented

TABLE 7.5.

cf. Aves Measurements (in mm)

Approximate measurements, due to broken tooth, represented by [ ]. If measurement not possible, represented by —. Denticle measurements were made on largest denticles present. Abbreviations: curvature (curv.); fore-aft basal length (FABL); height (Ht); cross-sectional thickness (CST); cross-sectional shape (CSS); denticles/mm (dent/mm); rd (round); dent (denticles); ht (height); wd (width); frag (fragment); ant. (anterior); post. (posterior); flat (flattened).

LSUM G Spec. No	L LSUM G ocal.	Geo. Fm.	Age	Curv.	FABL	HT	CST	CSS	A.Dents. present.	Dents/mm Post.	Dent. Wd.Post.	Dent. Ht. Post.
5995	113	Aguja	Ea. Maast.	[0.1]	1.2	[2.0]	0.7	ova/rd	none	none	none	none
5999	232	Tornillo	Maast	0.1	1	1.5	—	—	oval	none	none	none

at their base, with absent or minute denticles, some with a thin carina on both the anterior and the posterior edges, and oval to oval-flattened in cross section.

The two Big Bend specimens tentatively referred to bird are both from Maastrichtian sites. LSU 5995 is from the uppermost Aguja (LSU site 113), and LSU 5999 is from the lower Tornillo (LSU site 232). They are the first possible bird teeth reported from Big Bend.

Distinguishing bird teeth from small teeth of *Richardoestesia gilmorei* and *R. isosceles* can be difficult. However, *R. isosceles* teeth are not indented at the base; and *R. gilmorei* are more recurved, have larger denticles, and lack the distinctive hourglass of the base of the bird teeth (Sankey et al. 2002). Although Sankey et al. (2002) reported that the bird teeth from the Judith River Group of Alberta are similar to those from *Hesperornis*, they are also similar to those from some small non-avian dinosaurs (e.g., Xu et al. 2000). Therefore, referral of the Big Bend specimens to bird is tentative.

Discussion

Baszio (1997a) documented theropod relative abundance patterns from the mid-Campanian to upper Maastrichtian of Alberta based on large collections of theropod teeth from the RTMP and UALVP. Using cluster analysis of relative abundance of theropod taxa he found two groups. Assemblage B is the Dinosaur Park–Horseshoe Canyon cluster, characterized by abundant *Troodon* and few *Richardoestesia* sp. Assemblage A is the Milk River–upper Maastrichtian cluster, characterized by a relatively high abundance of *Richardoestesia* sp. and *Paronychodon*. Baszio (1997a) suggested that these two distinct assemblages occupied different geographic areas, and that the assemblages shifted north-south according to regional climatic changes or shifted coastal-inland according to transgressions and regressions. Thus, Baszio demonstrated that there were different theropod assemblages characteristic of certain paleoenvironmental and paleoclimatic conditions, and that the geographic areas these assemblages occupied shifted through time.

Within Big Bend, there also appear to be two distinct theropod assemblages, one late Campanian–early Maastrichtian and one Maastrichtian. The Campanian–early Maastrichtian theropod assemblage is from the upper Aguja, which is more coastal; this assemblage is characterized by a higher abundance of *Saurornitholestes* cf. *S. langstoni* and *Richardoestesia isosceles*. The Maastrichtian theropod assemblage is from the uppermost Aguja and lower Tornillo, which is more inland; this assemblage is characterized by a higher abundance of *Saurornitholestes* n. sp.? and *Paronychodon*.

The Judith River Group of Alberta is often considered the standard for late Campanian theropod diversity in North America. Sankey et al. (2002) recognized several new morphotypes that are possible new taxa, making theropod diversity in the Judith River Group even higher than previously recognized (Currie et al. 1990; Baszio 1997b). However, compared to the Judith River Group, Big Bend theropod diversity appears to be significantly lower. For example, *Troodon* and *Dromaeosaurus*, present in the Judith River Group, are absent from Big Bend. The reasons for Big Bend's lower diversity are not known. Additionally, valid comparisons between Big Bend and Alberta theropod diversity are difficult to make, owing to differences in paleogeography, depositional setting, outcrop area, and amount of collection effort.

Among the Big Bend theropods, there are some interesting patterns. For example, distinct morphotypes of *Saurornitholestes* may represent distinct species. This is supported by morphologic as well as stratigraphic information: teeth of *Saurornitholestes*. n. sp.? have been found only in the early Maastrichtian sites.

This sample of theropod teeth from Big Bend demonstrates that the theropod assemblages in this area were distinct from northern areas. More samples are needed to better characterize the differences in these taxa. The sample also demonstrates that there were distinct theropod assemblages in the Campanian and Maastrichtian of Big Bend. However, considerably more information is needed on the Maastrichtian theropods from Big Bend in order to document theropod diversity patterns during the last 10 million years of the Cretaceous of both Big Bend and across a wider geographic gradient in North America.

Conclusions

The theropods present in the Big Bend area are identified and compared to contemporaneous assemblages such as the Judith River Group of Alberta. This was accomplished by describing, illustrating, and measuring theropod teeth collected both by surface collecting and by screening of microsites in the upper Aguja (upper Campanian–lower Maastrichtian) and the lower Tornillo (Maastrichtian) formations of Big Bend. Variation within the theropods is documented, in particular with respect to *Saurornitholestes;* and the first possible *Paronychodon* and bird specimens are recorded from Big Bend. The presence of two theropod assemblages, one from the late Campanian–early Maastrichtian and one from the Maastrichtian, is also documented. Further work in Big Bend is needed in order to (1) test whether *Saurornitholestes* n. sp.? is a distinct taxon; (2) test whether *Troodon* and *Dromaeosaurus* were really absent; (3) determine more differences between the Campanian and Maastrichtian theropod assemblages; and (4) increase the number of samples of the new morphotypes reported here. This work will improve our knowledge of theropod assemblages from this southern biogeographic province and document how the assemblages changed during the last 10 million years of the Cretaceous, leading up to the K/T extinctions.

Acknowledgments. Sankey appreciates funding for her Big Bend work from the Dinosaur Society, Jurassic Foundation, Earthwatch Durfee Student Challenge Award, and South Dakota School of Mines and Technology's Haslem and Nelson Funds, and for her work in Alberta from the United States–Canada Fulbright Program. Funding to Schiebout supporting Standhardt's Big Bend research was obtained from the National Science Foundation. Standhardt appreciates field and lab help by LSU students during the 1980s. Sankey appreciates help in field and lab from Jean Sankey, students from LSU (1995–98), students from Earthwatch's Durfee Student Challenge Awards Program (2000), and students from SDSM&T (2002). Sankey's Big Bend National Park fieldwork was done under BBNP permit numbers BIBE-2000-046, 2001–SCI-0010, and 2002–SCI-0001. We thank Vidal Davilla, Don Corrick, and Rito Rivero for their assistance. Donald Brinkman and Philip Currie (Royal Tyrrell Museum of Palaeontology) taught Sankey about theropod teeth, and she appreciates their help and interest in this work. Illustrations were prepared by Lisa Pond (LSU).

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