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Cover photo: An isolated right tibia,TTU-P11175, is one of the novel basal theropod specimens from the Dockum Group of Texas. Specimen in end views (left) and side views (right).

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New Theropod Fossils from the Upper Triassic Dockum Group of Texas, USA, and a Brief Overview of the Dockum Theropod Diversity

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New records enrich the Late Triassic theropod assemblage of the Dockum Group of Texas. Here, five unpublished theropod specimens (TTU-P11175, TTU-P12531X, TTU-P12587X, TTU-P14786, TTU-P16789) are described, each represented by a single element and collected from various fossil localities of Garza County, Texas. Additionally, two previously described specimens (TTU-P10082, TTU-P10534), which were also recovered from Upper Triassic rocks of Garza County are revisited for additional remarks on their anatomy. These new theropod specimens increase the abundance and disparity of theropods in the Dockum terrestrial vertebrate fauna. Together, with confirmed theropod discoveries in other recent works, the newly evaluated specimens add to the long history of dinosaur research in the Dockum Group of Texas.

Keywords: Upper Triassic, Dockum, Texas, Garza, Dinosauria, Theropoda

INTRODUCTION

Although the Dockum Group is generally recognized for the dominance and large diversity of Late Triassic pseudosuchians, new discoveries and reappraisals of previous findings bring a new understanding to the Dockum dinosauromorph diversity in recent years (e.g., Irmis et al. 2007a, 2007b, Nesbitt et al. 2007, Nesbitt and Chatterjee 2008, Martz et al. 2013, Sarıgül 2016). Thus far, the confirmed Dockum dinosaur record in Texas is composed solely of theropod specimens collected from Garza and Howard counties (e.g., Lehman and Chatterjee 2005, Nesbitt et al. 2007, Nesbitt and Chatterjee 2008, Martz et al. 2013, Nesbitt and Ezcurra 2015). This paper will contribute to the fossil record of Dockum theropods in Texas by describing five new isolated specimens and providing further observations for two previously published specimens, all unearthed from Garza County. A short historical review of all the theropod specimens collected from the Dockum Group of Texas is presented at the end of this paper, excluding the controversial taxon *Protoavis texensis* Chatterjee, 1991.

GEOLOGICAL SETTING AND FOSSIL LOCALITIES

Deposited in the upstream portion of the huge Chinle-Dockum ancient river system (Riggs et al. 1996), the Dockum Group is broadly exposed in the western part of Texas and the eastern part of New Mexico, especially around the margin of the Staked Plains or Llano Estacado (Fig. 1). The thick fluvial deposits of the Upper Triassic Dockum Group of Texas measures up to 700 meters, these have been extensively prospected for fossils, and a basic lithostratigraphic framework established (e.g., Chatterjee 1986, Lucas and Hunt 1989, Lehman et al. 1992, Lehman 1994a, 1994b, Lucas and Anderson 1995, Lehman and Chatterjee 2005). This framework consisted of four units; namely the Santa Rosa, Tecovas, Trujillo and Bull Canyon formations. However, problems with the unit boundaries required a new lithostratigraphic subdivision for the coeval strata in Garza County, Texas. Accordingly, the name Cooper Canyon Formation (once incorrectly used as a replacement for the Bull Canyon Formation) is employed for the whole sequence overlying the Santa Rosa Formation in Garza County (Martz 2008, Martz et al. 2013). Nevertheless, the lower, middle and upper units of the Cooper Canyon Formation in Garza County are direct correlatives of Tecovas, Trujillo and Bull Canyon formations of the classical scheme, which still provides a valid partition for the Upper Triassic red beds in northern Texas and eastern New Mexico counties (Fig. 2).

Alternatively, the examination of the Trujillo and Tecovas in Crosby County demonstrates that these formations are lithologically no different than the lower and middle units of

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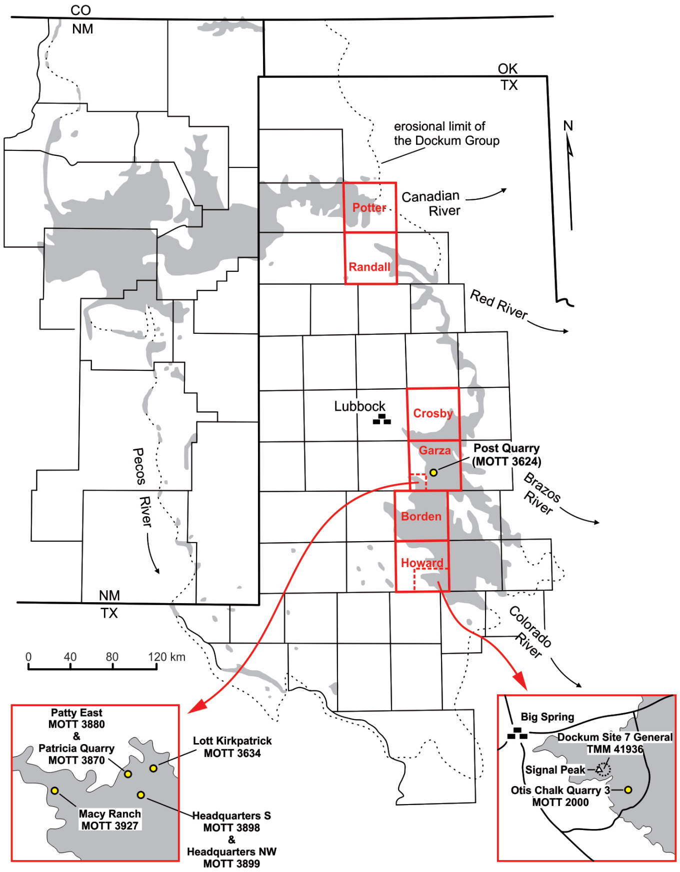

Figure 1. Exposures of the Dockum Group (highlighted in grey) in western Texas and eastern New Mexico (modified after Lehman 1994a). Borders of all county quadrangles discussed within the text are highlighted in red, whereas the cited fossil localities are marked with yellow-filled circles within the Garza and Howard County quadrangles. The approximate position of Dockum Site 7 General (TMM 41936) in close-up view of Howard County is modified after Nesbitt and Ezcurra (2015).

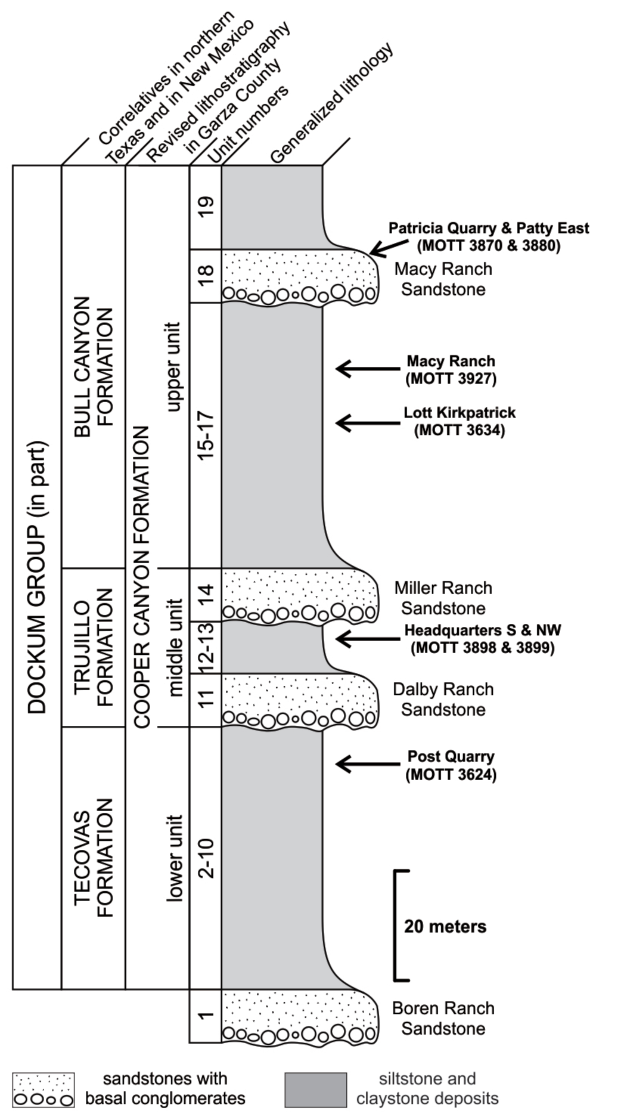

Figure 2. Simplified columnar section of the Dockum Group in Garza County, Texas, including the stratigraphic positions of the dinosaur-bearing quarries in bold (modified after Martz 2008, Martz et al. 2013).

the proposed Cooper Canyon Formation in Garza County, which makes the former names not only correlatives but also senior synonyms (Bill Mueller, personal communication, 2016). Here, there is no intention to take a side in this current debate, but a standardization of terminology is desperately needed for the lithostratigraphy of the Dockum Group of Texas, similar to what was recently provided for the Upper Triassic of New Mexico (Cather et al. 2013). Such a comprehensive framework would resolve the disagreement either in abandonment of the different suggestions on lithostratigraphy in different parts of western Texas (e.g., Lucas and Anderson 1995, Martz et al. 2013) in favor of the classical Santa Rosa-Tecovas-Trujillo-Bull Canyon succession, or integration of different stratoypes into the Dockum Group as local correlatives.

The fossil specimens examined in this study were collected from seven different fossil localities in Garza County (Figs. 1–3). The lowermost quarry in this study, the Post Quarry (MOTT 3624) produced the most diverse terrestrial tetrapod assemblage among all of the Garza localities and it corresponds stratigraphically to the upper part of the lower unit of the Cooper Canyon Formation (Martz et al. 2013). The overlying fossil sites also yield different vertebrate taxa, including numerous archosaurs, and their stratigraphic positions within the Dockum Group have been provided recently (Martz 2008). The Headquarters South (MOTT 3898) and Headquarters Northwest (MOTT 3899) localities are placed at the upper levels of the middle unit of the Cooper Canyon Formation. Patricia Quarry (MOTT 3870) and Patty East (MOTT 3880) are located near the top of the

Taxon	Voucher	Elements
Theropoda?		
	UMMP 8870	Right ilium
Theropoda		
Herrerasauridae		
Chindesaurus bryansmalli	TMM 31100-532	Proximal end of left femur
Herrerasauridae indet.		
	TTU-P10082	Partial left ilium, left pubis
	TTU-P12531X	Proximal end of right femur
	TTU-P16789	Posterior dorsal vertebra
Theropoda indet.		
	TMM 31100-545	Right femur
	TMM 31100-1324	Right tibia
	TTU-P10072	Partial postcranial skeleton
	TTU-P11175	Right tibia
	TTU-P12587X	Proximal end of left femur
Neotheropoda		
Lepidus praecisio	TMM 41936-1.3	Articulated distal ends of left tibia and fibula, and left astragalocalcaneum (holotype)
	TMM 41936-1	Fragment of left femoral shaft
	TMM 41936-1.1	Partial left maxilla
Neotheropoda indet.		
	TTU-P10071	Right ilium, without anterior process
	TTU-P10534	Right tibia
	TTU-P11044	Right tibia
	TTU-P14786	Distal end of left tibia

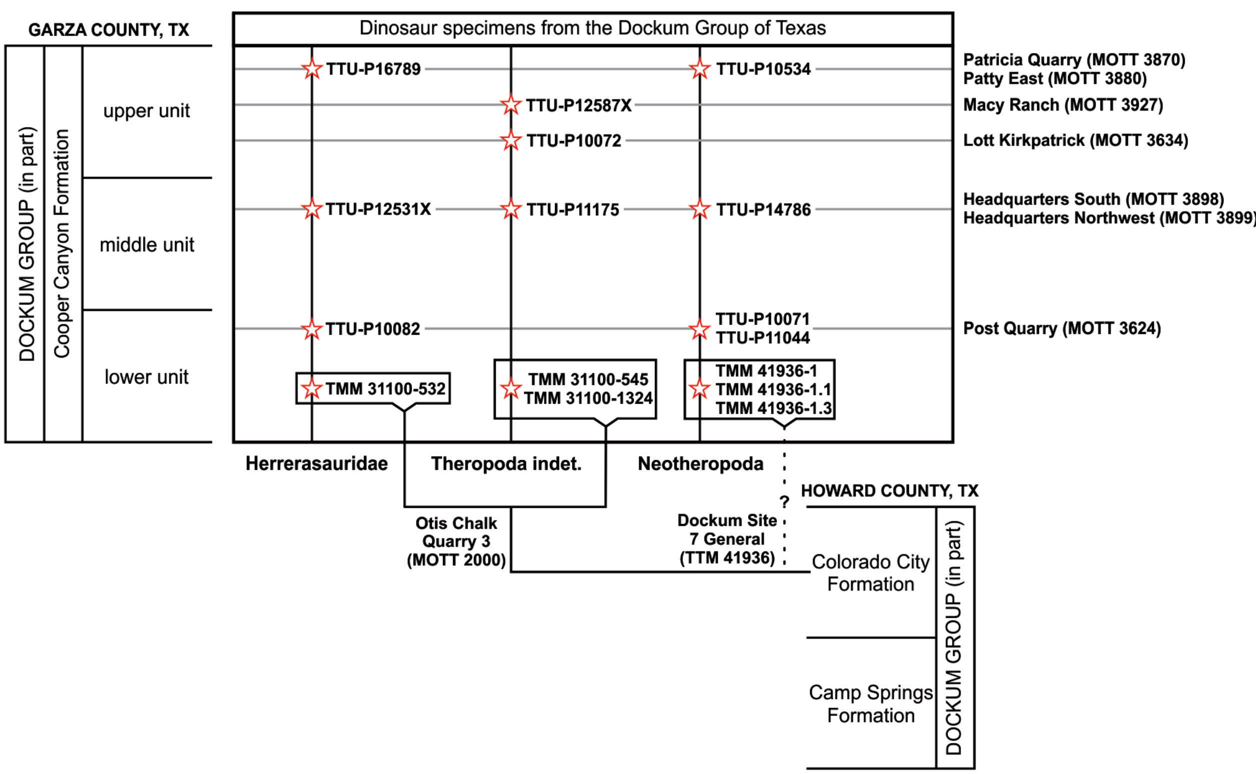

Figure 3. Complete listing of published Dockum dinosaur vouchered specimens, except the controversial taxon *Protoavis texensis*. Stratigraphic sections simplified after Lucas and Anderson (1993) and Martz et al. (2013). Lithologic thicknesses are not to scale. Note that the exact collection location of the specimen UMMP 8870 of Case (1927) is unknown.

Macy Ranch Sandstone (Martz 2008), whereas the Macy Ranch (MOTT 3927) lies about 20–25 meters below Macy Ranch Sandstone, and the Lott Kirkpatrick (MOTT 3634) locality is placed about 10 meters below the Macy Ranch fossil quarry (Martz 2008).

Two other dinosaur fossil producing localities are located in Howard County: Otis Chalk Quarry 3 (MOTT 2000) and Dockum Site 7 General (TMM 41936) near Signal Peak, which is located northwest of the Otis Chalk Quarry 3 (Figs. 1, 3). The various Otis Chalk quarries are situated low in the Dockum Group and the stratigraphic placement of Dockum Site 7 General is provisionally accepted to be close to the Otis Chalk Quarries based on their faunal assemblages (Nesbitt and Ezcurra 2015, Sarıgül 2016) (Fig. 3). Nevertheless, the lithostratigraphic correlation of Dockum Group strata between Garza and Howard counties is not robustly supported as mentioned above.

MATERIALS AND METHODS

There are seven theropod specimens described in this work. Five of them (TTU-P11175, TTU-P12531X, TTU-P12587X, TTU-P14786 and TTU-P16789) are previously unreported specimens and each is represented by a single bone. The formerly described specimen TTU-P10082 consists of pelvic fragments (Lehman and Chatterjee 2005, Nesbitt and Chatterjee 2008, Martz et al. 2013) and some remarks will be made here on the postacetabular portion of the ilium. Furthermore, a more detailed description for the previously published specimen, TTU-P10546, is provided for the first time. All of the new specimens treated in this work were collected from Garza County, Texas by Bill Mueller and Doug Cunningham in the first decade of the 21st century, and together with previously published theropod specimens from the Dockum Group of Texas, are reposited in the collections of the Museum of Texas Tech University with a specific voucher number pertaining to the palaeontology division of the museum (viz. TTU-P). All the bones were mechanically prepared, adhesives applied to the fractured parts and cellulose sculpting medium used to complete the large fractures and missing portions of TTU-P10082 and TTU-P10534. Preliminary information for these specimens was incorporated into a PhD dissertation dealing with the Dockum dinosauromorphs of Texas, together with other published or unpublished dinosauromorph specimens from the Museum of Texas Tech University (see Sarıgül 2014).

In this study, the term basal theropods define the non-neotheropod members of Theropoda Marsh, 1881 and herrerasaurids, and they are considered to be a monophyletic clade that includes *Herrerasaurus ischigualastensis* Reig, 1963 and *Staurikosaurus pricei* Colbert, 1970 (e.g., Benedetto 1973, Novas 1992, Rauhut 2003, Nesbitt 2011). *Chindesaurus bryansmalli* Long and Murry, 1995 was originally defined as a herrerasaurid and this assignment is supported by various cladistic analyses, and is adopted here (e.g., Nesbitt et al. 2009, Langer et al. 2011). A possible recovery of *Chindesaurus* as a taxon more closely related to neotheropods is suggested after the discovery of *Lepidus praecisio* Nesbitt and Ezcurra, 2015, but this novel placement depends on which specimens are referred to *L. praecisio* (Nesbitt and Ezcurra 2015).

Institutional Abbreviations—MCZ: Museum of Comparative Zoology, Harvard University; **MOTT**: prefix for Museum of Texas Tech University localities; **PEFO**: Petrified Forest National Park, Arizona; **PVSJ**: Museo de Ciencias Naturales, Universidad Nacional de San Juan; **TTU-P**: prefix for Museum of Texas Tech University specimens; **NMMNH**: New Mexico Museum of Natural History; **TMM**: Texas Memorial Museum; **UMMP**: University of Michigan Museum of Paleontology.

SYSTEMATIC PALEONTOLOGY

DINOSAURIA Owen, 1842 *sensu* Padian and May, 1993
SAURISCHIA Seeley, 1887 *sensu* Gauthier, 1986
THEROPODA Marsh, 1881 *sensu* Gauthier, 1986
HERRERASAURIDAE Benedetto, 1973
Figs. 4–8

Referred specimens— TTU-P10082, nearly complete left pubis and postacetabular process of left ilium with a proximal fragment of the ischium attached; TTU-P12531X, proximal end of right femur; TTU-P16789, posterior dorsal vertebra.

Localities— The referred specimens were collected from the Garza County localities of Post Quarry (MOTT 3624), Headquarters South (MOTT 3898) and Patricia Quarry (MOTT 3870), respectively (Figs. 1, 2).

Horizons—Post Quarry is situated at the lower unit of the Cooper Canyon Formation (*sensu* Martz 2008), Headquarters South (MOTT 3898) is placed in the middle unit of the Cooper Canyon Formation (*sensu* Martz 2008), whereas Patricia Quarry (MOTT 3870) horizon falls within the upper unit of the Cooper Canyon Formation (*sensu* Martz 2008) (Fig. 3).

Description and remarks

TTU-P10082—This specimen is a rectangular, low and robust postacetabular (or posterior) process of the left ilium and a left pubis with the pubic peduncle attached (Figs. 4A, B, 5A–D). TTU-P10082 was previously described in detail (Nesbitt and Chatterjee 2008, Martz et al. 2013), and shown to represent an undetermined herrerasaurid. But a closer look at the postacetabular process of the ilium suggests a

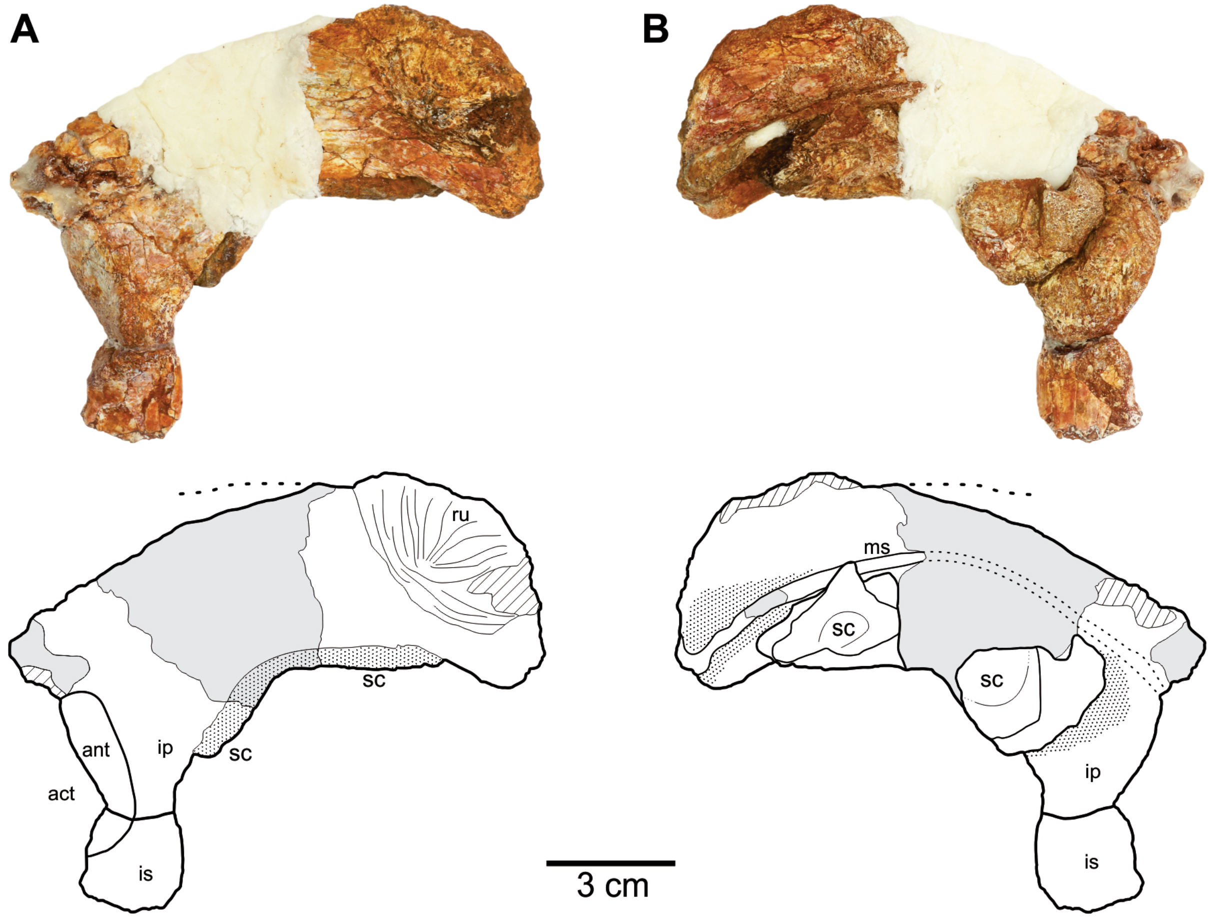

Figure 4A, B. Dockum herrerasaurid, iliac postacetabular process, TTU-P10082. **A.** Left postacetabular process in lateral view. **B.** Medial view. Abbreviations: **act**, acetabulum; **ant**, antitrochanter; **ip**, ischial peduncle; **is**, ischium; **ms**, medial shelf; **ru**, rugose surface; **sc**, sacral rib. Hatching indicates the damaged areas; portions in grey represent cellulose sculpting medium.

different anatomical reconstruction. The anterior fragment of this element is composed of an antitrochanter and an ischial peduncle, where the posterior fragment represents the posterior iliac blade, including a medial shelf (*sensu* Hutchinson, 2001). These two fragments were glued together assuming that they were adjacent pieces, on which the pelvic reconstructions of TTU-P10082 are based (Nesbitt and Chatterjee 2008, figs. 1c and 1d; Martz et al. 2013, figs. 15a and 15b). However, the boundary between the two fragments is discontinuous at the ventral border in lateral view, indicating that there is a missing portion in-between (Fig. 6A). The missing part between the two iliac fragments likely housed the origin for M. caudofemoralis brevis. But more importantly, the assumed reconstruction from the previous papers creates an anatomically implausible position for the posterior portion of the bone, where the sacral ribs aligned in posterodorsal-anteroventral direction and deviated at a 35° angle from the anteroposterior axis (Fig. 6B).

A hypothetical restoration of the postacetabular process with a continuous ventral border and aligned sacral vertebrae is presented here (Fig. 6C, D). The sacral column of herrerasaurids is more or less straight in anteroposterior direction (e.g., Sereno and Novas 1992, Alcober and Martinez 2010) and this vertebral alignment is emphasized here in the reconstruction of TTU-P10082. Another parameter is the correct placement of the iliac antitrochanter, which is located on the posterior side of the acetabulum (Novas 1996). The morphology of the postacetabular process now becomes very similar to an iliac fragment (UMMP 8870) referred to a North American herrerasaurid (Long and Murry 1995, Novas 1997, Hunt et al. 1998) or at least to a North American dinosaur (Nesbitt and Chatterjee 2008). TTU-P10082 and UMMP 8870 share a long and low postacetabular process with the posterodorsal rugosity (that is significantly larger in TTU-P10082), and also a pronounced shelf on the medial side of the bone that is concurrent with the lack of a brevis fossa (Nesbitt et al. 2007). Although no attached sacral vertebrae were found on UMMP 8870, it is hypothesized that

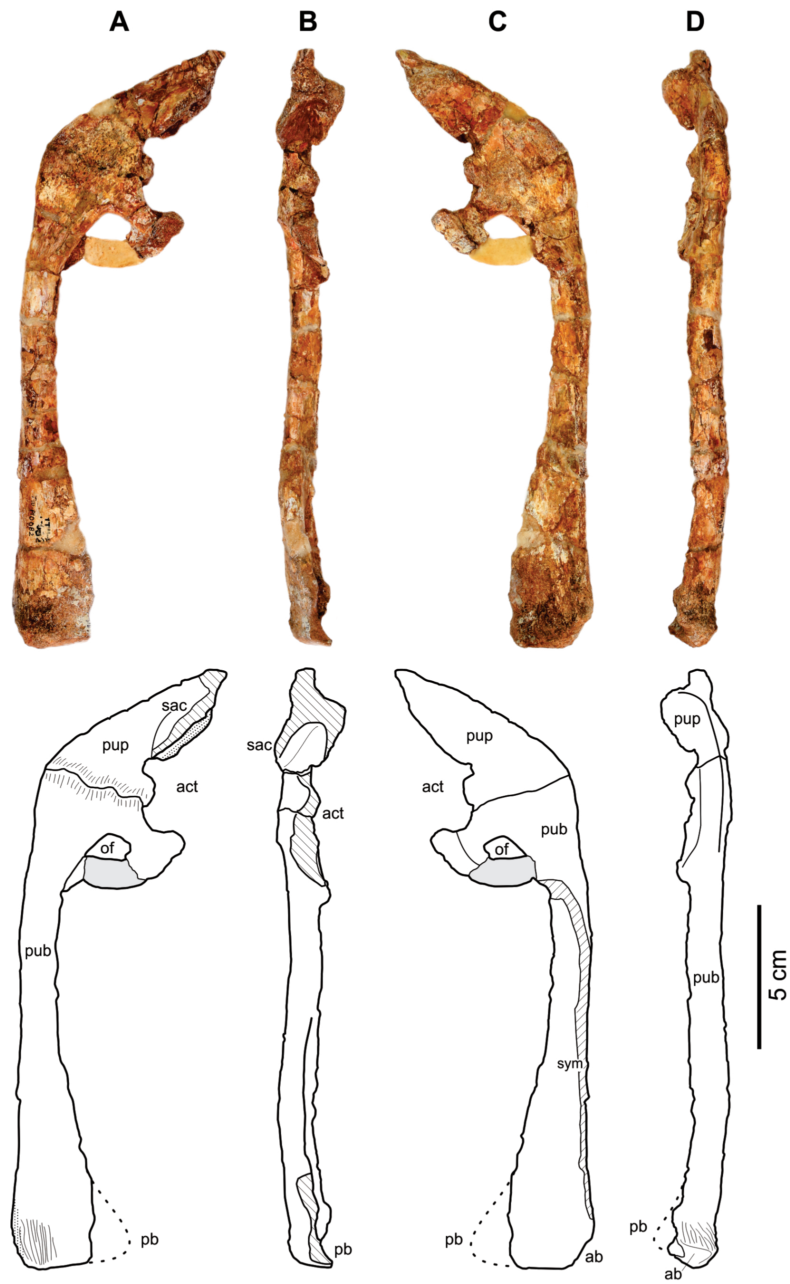

Figure 5A–D. Dockum herrerasaurid, pubis and attached pubic peduncle, TTU-P10082. **A.** Left pubis and pubic peduncle in lateral view. **B.** Posterior view. **C.** Medial view. **D.** Anterior view. Abbreviations: **ab**, anterior bevel; **act**, acetabulum; **of**, obturator fenestra; **pb**, pubic boot; **pub**, pubis; **pup**, pubic peduncle; **sac**, supraacetabular crest; **sym**, symphysis for pubic apron. Hatching indicates the damaged areas; portions in grey represent cellulose sculpting medium.

this specimen possesses the ancestral state of having only two sacral vertebrae because of the small size of the postacetabular process (Long and Murry 1995), where the medial shelf serves as a dorsal support only for the second sacral rib (Langer 2004). However, the two sacral ribs found attached on the postacetabular process indicates that TTU-P10082 possibly had a minimum of three sacral vertebrae since the first primordial sacral rib in early theropods is always placed anterior to the ischial peduncle, generally around the acetabular area (Novas 1996, Nesbitt and Chatterjee 2008). This situation implies that UMMP 8870 might have had three sacrals as well. Unlike the almost horizontal medial shelf of UMMP 8870, the medial shelf of the reconstructed TTU-P10082 postacetabular process exhibits slight posteroventral deflection; however, this appears to be a homoplastic trait as a similar kind of curvature is also present in medial shelves of

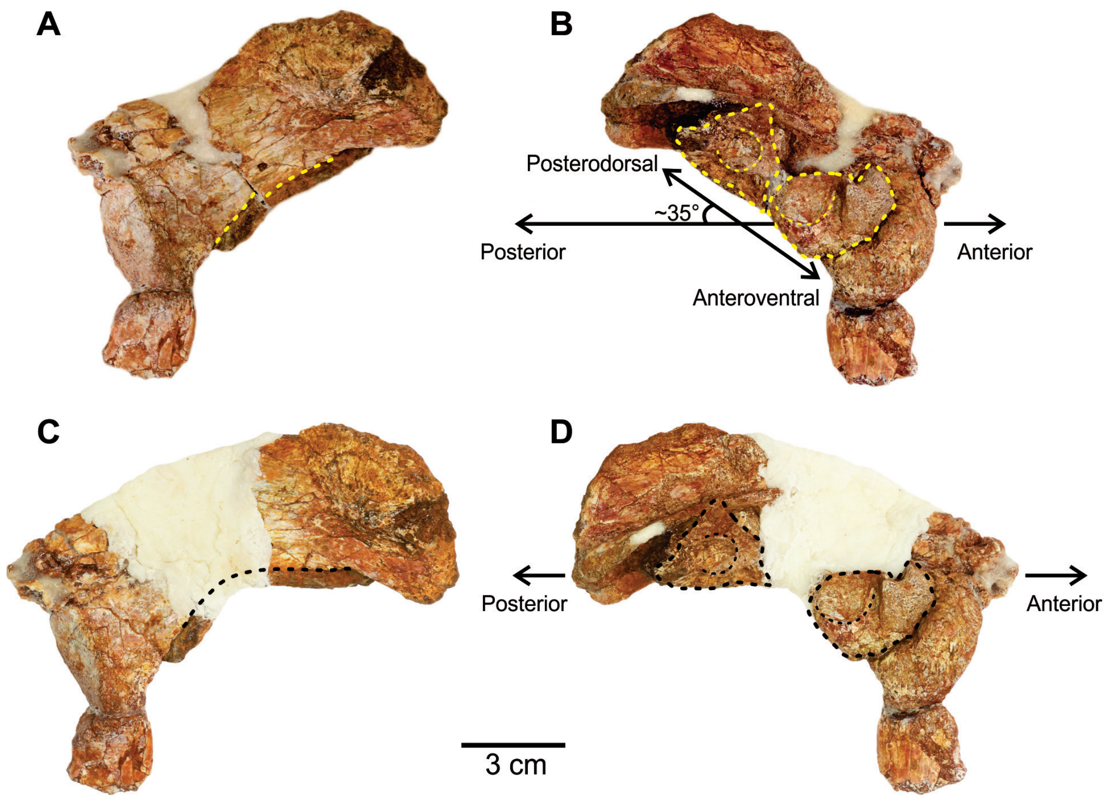

Figure 6A–D. Two interpretations for the postacetabular process of Dockum herrerasaurid (TTU-P10082). **A, B.** The reconstruction in previous works of Nesbitt and Chatterjee (2008) and Martz et al. (2013), in lateral and medial views. **C, D.** The reconstruction in this study in lateral and medial views. Note that the dashed lines in yellow demonstrate the discontinuous ventral margin and the non-horizontal alignment of the sacral vertebrae; whereas the black dashed lines suggest a more plausible morphology, as discussed in the text.

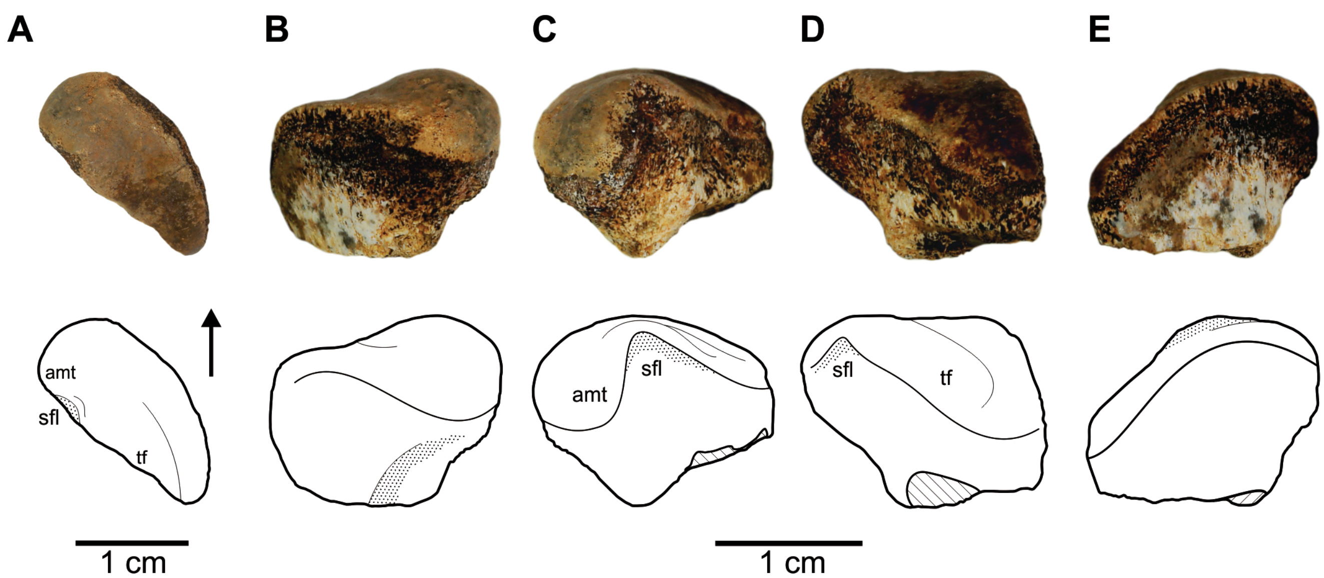

Figure 7A–E. Dockum herrerasaurid, proximal end of right femur, TTU-P12531X. **A.** Partial femur in proximal view. **B.** Anterior view. **C.** Medial view **D.** Posterior view. **E.** Lateral view. Abbreviations: **amt**, anteromedial tuber; **tf**, trochanteric fossa; **sfl**, sulcus for femoral ligament. Proximal view has its own scale. Hatching indicates the damaged areas. Arrow indicates anterior side for the proximal (**A**) view.

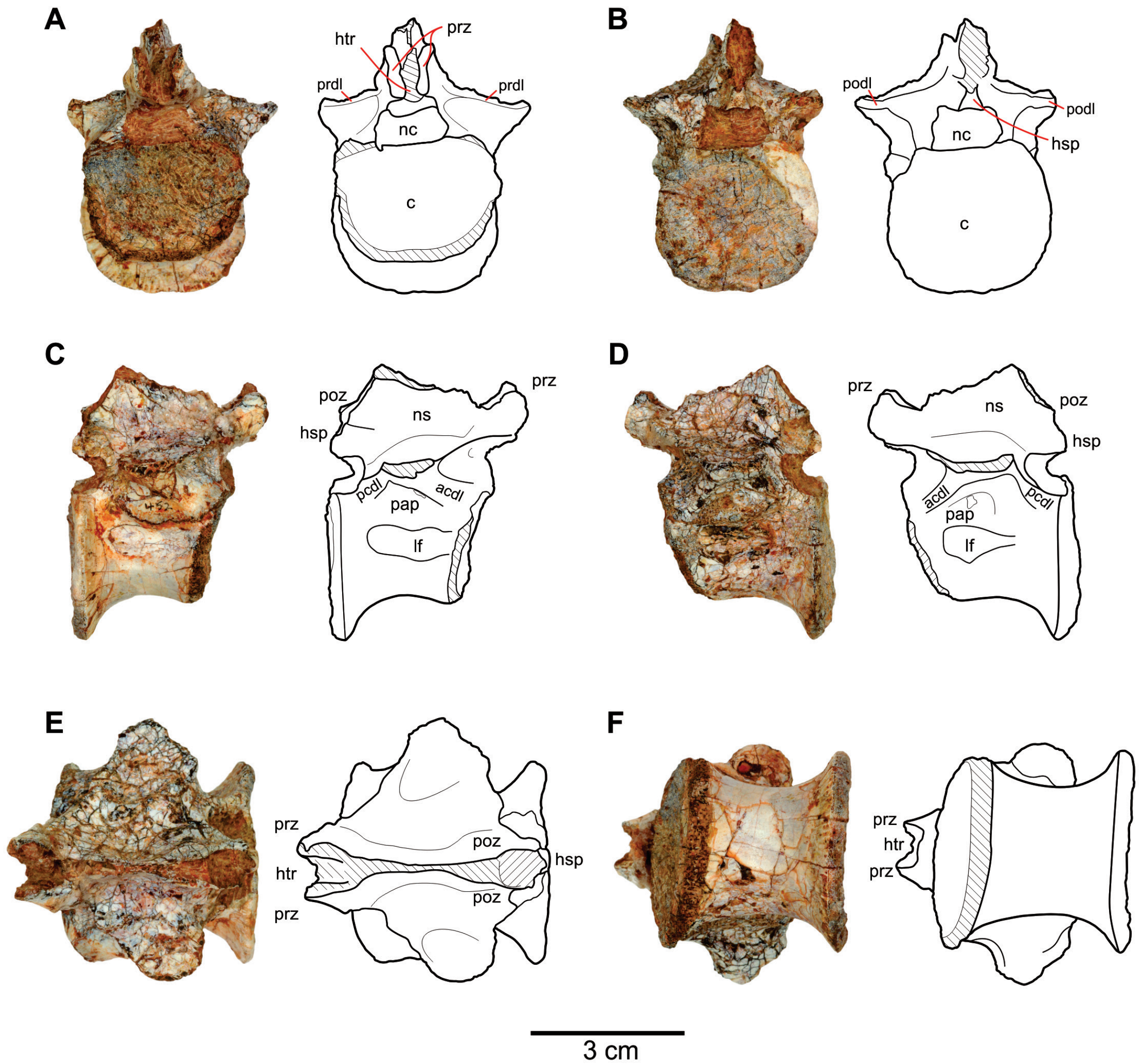

Figure 8A–F. Dockum herrerasaurid, posterior dorsal vertebra, TTU-P16789. **A.** Vertebra in anterior view. **B.** Posterior view. **C.** Right lateral view. **D.** Left lateral view. **E.** Dorsal view. **F.** Ventral view. Abbreviations: **acdl**, anterior centrodiapophyseal lamina; **c**, vertebral centrum; **hsp**, hyposphene; **htr** hypantrum; **lf**, lateral fossa; **nc**, neural canal; **pap**, parapophysis; **pcdl**, posterior centrodiapophyseal lamina; **podl**, postzygodiapophyseal lamina; **poz**, postzygapophysis; **prdl**, prezygodiapophyseal; **prz**, prezygapophysis. Hatching indicates the damaged areas.

dromaeosaurids, e.g, *Deinonychus antirrhopus* Ostrom, 1969 (MCZ 4371, MCZ 4142), *Bambiraptor feinbergi* Burnham et al., 2000 (Burnham 2004) and *Mahakala omnogovae* Turner et al., 2007. Unfortunately, the iliac blades of all Triassic ornithodirans found in southwestern North America are missing different portions and therefore, a taxonomic assignment to genus for TTU-P10082 cannot be made (Nesbitt and Chatterjee 2008, pp. 145–146).

TTU-P12531X—The periphery of the proximal surface of this right femur is slightly eroded (Fig. 7A). The anteromedial tuber of the femoral head (*sensu* Nesbitt 2011) is small and well rounded (Fig. 7B, C), whereas the posteromedial and anterolateral tubera are not visible (Fig. 7D, E). The shallow femoral ligament (ligamentum capitis femoris) groove creates a distinct notch on the anteromedial side of the proximal surface as is typical of a dinosauriform femur (Novas 1996, Rauhut 2003: character 197). The helical trochanteric fossa, or fossa trochanterica *sensu* Langer (2004) is highly developed and expanded over the proximal surface, where it obliterates the typical longitudinal groove of dinosauriforms on the proximal surface of the femur (Fig. 7A, D).

Presence of a trochanteric fossa is a good synapomorphy for Dinosauromorpha, but this character occurs homoplastically in the proximal femur of shuvosaurids, which differs from the dinosauromorph femur by possesing a distinctly recurved anteromedial tuber (Nesbitt 2011: characters 300, 313). Having a small anteromedial tuber and a reduced posteromedial tuber are diagnostic for dinosauriforms, except *Tawa hallae* Nesbitt et al., 2009 and neotheropods (Novas 1996: character 28; Nesbitt 2011: characters 300, 301; Langer et al. 2013). However, the two characters described in TTU-P12531X, a reduced anterolateral tuber and an over-expanded trochanteric fossa, are very uncommon among dinosauriforms. The absence of an anterolateral tuber is recognized only in lagerpetids and in *Herrerasaurus* (PVSJ 373) and *Chindesaurus* (PEFO 10395) among early dinosauriforms (Nesbitt et al. 2009, character 225, Nesbitt 2011: character 302). Moreover, *Herrerasaurus* and *Chindesaurus* also lack the longitudinal groove on the proximal surface of the femur due to the over-expansion of the trochanteric fossa (Langer 2004, Nesbitt and Chatterjee 2008, Nesbitt 2011: character 314). The absence of this groove is described in another herrerasaurid, *Sanjuansaurus gordilloi* Alcober and Martinez, 2010, although it lacks a trochanteric fossa. Unlike TTU-P12531X and *Herrerasaurus*, *Chindesaurus* is missing the femoral ligament groove (Long and Murry 1995). Although the preserved portion is so inadequate to provide a more definitive diagnosis, the morphology of TTU-P12531X indicates a close resemblance to *Herrerasaurus*.

TTU-P16789—This specimen is a fairly complete vertebra, except for the damaged anterior centrum face and broken tips of the transverse processes and that of the neural spine (Fig. 8A–F). The neural arch retains the saurischian synapomorphy of a hyposphene-hypantrum accessory intervertebral articulation (Gauthier 1986), and principal diapophyseal laminae described in saurischians, namely anterior centrodiapophyseal (acdl), posterior centrodiapophyseal (pcdl), prezygodiapophyseal (prdl) and postzygodiapophyseal (podl) laminae on the transverse processes (Wilson 1999) (Fig. 8A–D). Vertebral laminae are one of the important saurischian features; however, the neural arch is too damaged to diagnose all the characteristic laminae with certainty. Tiny ridges decorate the periphery of the posterior end. The centrum is anteroposteriorly short and spool shaped, which is diagnostic in herrerasaurid dorsal centra (Novas 1992, Langer and Benton 2006). The parapophyseal facet for the rib attachment is not located on the centrum but closer to the neural spine, a situation that indicates TTU-P16789 is a posterior dorsal vertebra. There is also a blind fossa on each side (Fig. 8C, D). These types of shallow excavations on dorsal vertebrae are previously documented in *Herrerasaurus* (Novas 1993), *Chindesaurus* (Long and Murry 1995), many other dinosauriforms (Rauhut 2003, character 106), and various archosauriforms (e.g., Alcober and Parrish 1997, Parker and Barton 2008), but they do not represent the true pleurocoels of derived saurischians, which pierce the vertebral centra (e.g., Wedel 2007).

As a result of convergent evolution, both diapophyseal laminae and hyposphene-hypantrum articulation also occur in some paracrocodylomorphs (e.g., Wilson 1999, Weinbaum 2013) and some aetosaurs (e.g., Parker 2008, Desojo et al. 2012). However, the vertebral centra are relatively elongated in paracrocodylomorphs (*sensu* Nesbitt 2011) rather than being spool shaped (e.g., *Postosuchus kirkpatricki* Chatterjee, 1985 [TTU-P09002]) and both rib facets are on the transverse process of the dorsal vertebrae in aetosaurs. Parapophyses are located on the neural arch of dorsal vertebrae, and both zygapophyses and hyposphene-hypantrum articulations are relatively gracile in herrerasaurids, similar to what is observed for TTU-P16789.

THEROPODA MARSH, 1881 *SENSU* GAUTHIER, 1986
FIGS. 9, 10

Referred specimens—TTU-P11175, complete right tibia; TTU-P12587X, proximal end of left femur.

Localities—TTU-P11175 has been discovered in Headquarters Northwest (MOTT 3899) and TTU-P12587X was unearthed from Macy Ranch (MOTT 3927), Garza County, Texas (Figs. 1, 2).

Horizons—Headquarters Northwest (MOTT 3899) is placed in the middle unit of the Cooper Canyon Formation (*sensu* Martz 2008) and Macy Ranch (MOTT 3927) is located in the upper unit of the Cooper Canyon Formation (*sensu* Martz 2008) (Fig. 3).

Description and remarks

TTU-P11175—The slender right tibia has a sub-triangular proximal surface, including a crescentic cnemial crest with a smooth tibial notch and distinct medial and lateral condyles (Fig. 9A). The curvature of the cnemial crest does not reach to the lateral border (Fig. 9B). The medial border is slightly elevated; the rest of the proximal surface is mostly flat (Fig. 9A, C). The posterior condyles are aligned posteriorly and separated by a shallow intercondylar notch (Fig. 9D). These two distinctive basal theropod characters are also shared by *Silesaurus opoloensis* Dzik, 2003 and *Sacisaurus agudoensis* Ferigolo and Langer, 2007; posterior margins of the condyles are contiguous in *Eucoelophysis baldwini* Sullivan and Lucas, 1999, whereas the posterior condyles of neotheropods are separated by a deeper cleft (Rauhut 2003: character 205; Ezcurra 2006: character 250; Langer and Benton 2006: character 85; Nesbitt 2011: character 331). The medial condyle is somewhat larger than the lateral (fibular) condyle, which has a flattened lateral surface as in *Herrerasaurus*, *Staurikosaurus*, *Tawa* and some other neotheropods (Nesbitt 2011: character 332) (Fig. 9E). Unlike *Silesaurus*, *Sacisaurus* and neotheropods, no fibular crest is present (Nesbitt et al. 2009,

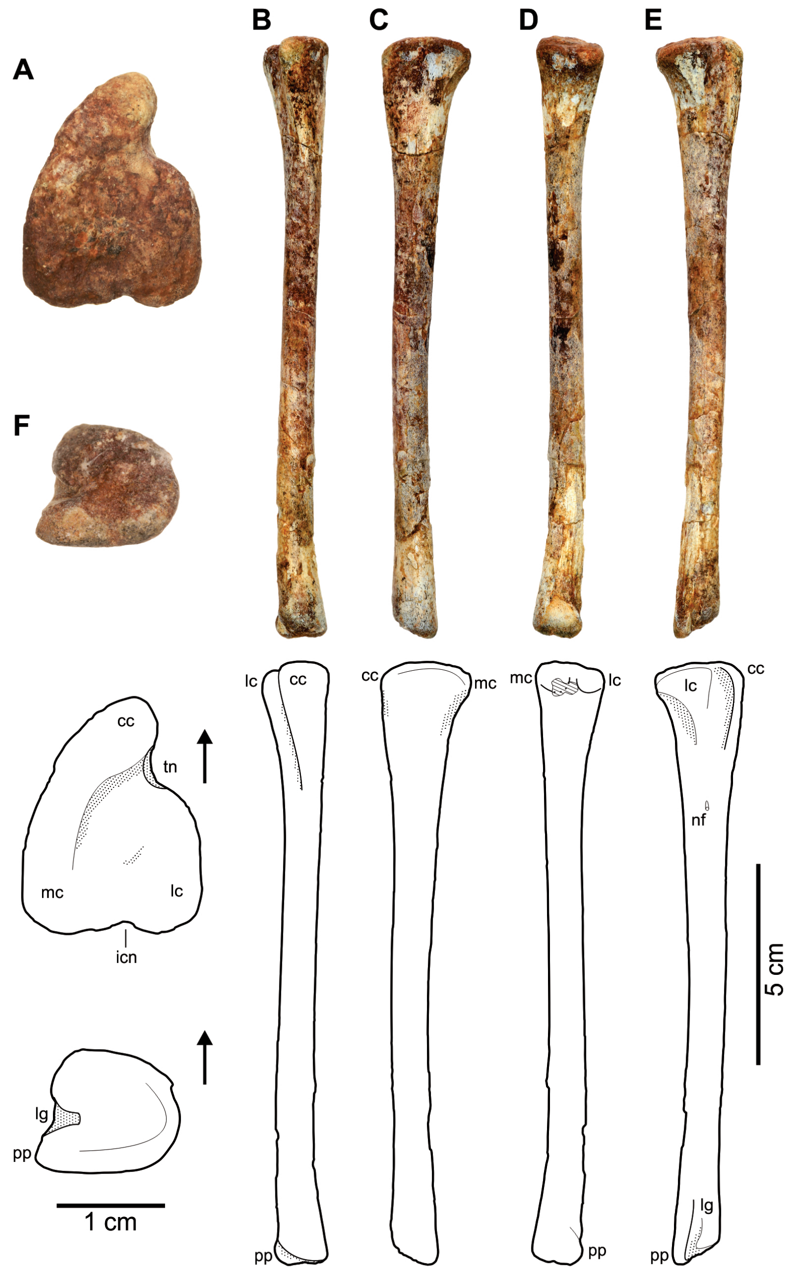

Figure 9A–F. Dockum basal theropod, right tibia, TTU-P11175. **A.** Tibia in proximal view. **B.** Anterior view. **C.** Medial view **D.** Posterior view. **E.** Lateral view. **F.** Distal view. Abbreviations: **cc**, cnemial crest; **icn**, intercondylar notch; **lc**, lateral condyle; **lg**, longitudinal groove (that gave rise to the distal notch); **mc**, medial condyle; **nf**, nutrient foramen; **pp**, posterior process; **tn**, tibial notch. Proximal and distal views share the 1 cm. scale bar. Hatching indicates the damaged areas. Arrow indicates anterior side for the proximal (**A**) and distal (**F**) views.

Nesbitt 2011). The shaft is hollow and rounded in transverse section and gets somewhat waisted towards the distal end without any noticeable structure, except the nutrient foramen located below to the lateral condyle. The distal end bears a longitudinal groove, contiguous with the ventrolateral notch (*sensu* Novas 1989) on the distal surface for the reception the ascending process of the astragalus (Fig. 9F). The ventrolateral notch does not deeply penetrate into the sub-rounded distal surface that possesses a small posterior process, matching the basal theropod condition (e.g., Novas 1989, 1996, Rauhut 2003: character 208; Langer and Benton 2006: character 87; Nesbitt 2011: characters 335, 336, 338).

TTU-P12587X—This specimen is the proximal end of a left femur. The femoral head is rounded and all three proximal tubera (*sensu* Nesbitt 2011) are recognized on the proximal surface (Fig. 10A). The anteromedial tuber is well

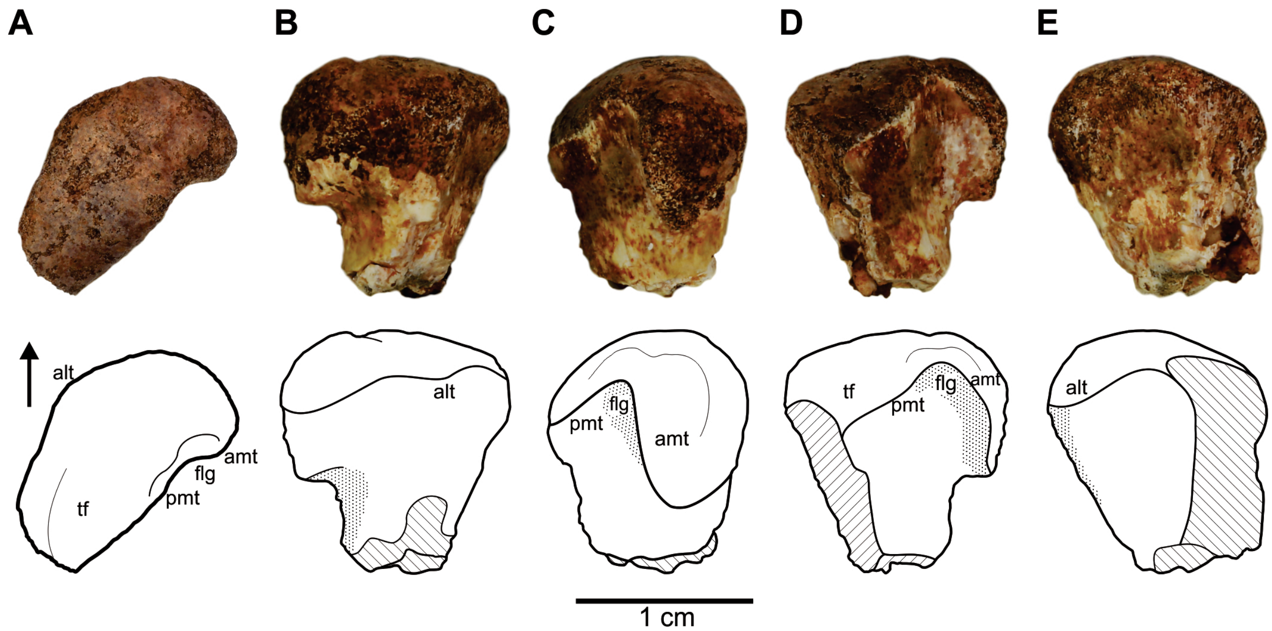

Figure 10A–E. Dockum basal theropod, proximal end of left femur, TTU-P12587X. **A.** Partial femur in proximal view. **B.** Anterior view. **C.** Medial view. **D.** Posterior view. **E.** Lateral view. Abbreviations: **alt**, anterolateral tuber; **amt**, anteromedial tuber; **flg**, femoral ligament (ligament femoris capitis) groove; **tf**, trochanteric fossa; **pmt**, posteromedial tuber. Hatching indicates the damaged areas. Arrow indicates anterior side for the proximal (**A**) view.

developed and expanded medially as in *Tawa* and neotheropods; where the anterolateral and posteromedial tubera are also pronounced as well as the groove for the ligament femoris capitis (Rauhut 2003: character 197, Nesbitt 2011: characters 300–302) (Fig. 10B–D). The posterolateral portion of TTU-P12587X, including part of the trochanteric fossa (i.e., facies articularis antitrochanterica), is missing (Fig. 10D, E).

TTU-P12587X has almost the same suite of character states with the femur of TTU-P10072, another Dockum specimen that was assigned to a basal theropod, closer to neotheropods than herrerasaurids (Nesbitt and Chatterjee 2008). TTU-P12587X differs from TTU-P10072 by the smaller size and in lacking a longitudinal groove on the proximal surface.

THEROPODA Marsh, 1881 *sensu* Gauthier, 1986
NEOTHEROPODA Bakker, 1986 *sensu* Sereno, 1998
Figs. 11, 12

Referred specimens—TTU-P10534, left tibia; TTU-P14786, distal end of left tibia.

Localities—TTU-P10534 was collected from Patty East (MOTT 3880) and TTU-P14786 was found in Headquarters South (MOTT 3898), both in Garza County, Texas (Figs. 1, 2).

Horizons—Upper unit of the Cooper Canyon Formation (*sensu* Martz 2008) for the former quarry, middle unit of the Cooper Canyon Formation (*sensu* Martz 2008) for the latter quarry (Fig. 3).

Description and remarks

TTU-P10534—The proximal surface of TTU-P10534 is sub-triangular, anteroposteriorly longer than wide and slightly eroded around the edges (Fig. 11A). An elongated groove on the medial edge and a depression on the central part of the proximal surface probably served as an insertion point for some ligaments occurring between the femur and tibia. This central depression not only demarcates the cnemial crest from the posterior condyles, but it also extends between the two condyles. The anterior part of the cnemial crest is slightly damaged and weakly bent towards the fibular side, leaving the smooth-surfaced tibial notch uncovered (Fig. 11B). A well-developed fibular crest is present on the lateral side that gradually projects towards the distal portion (Fig. 11B, C). Both condyles are pronounced where the lateral (or fibular) condyle is rounded and slightly smaller than the medial condyle, which possesses a proximally oriented medial edge (Fig. 11D, E). The posterior margins of the condyles are contiguous. The sub-circular shaft is broken just below the proximal head, where the nutrient foramen should be located, and was restored with cellulose sculpting medium. The shaft is slightly bowed to the medial side due to taphonomic

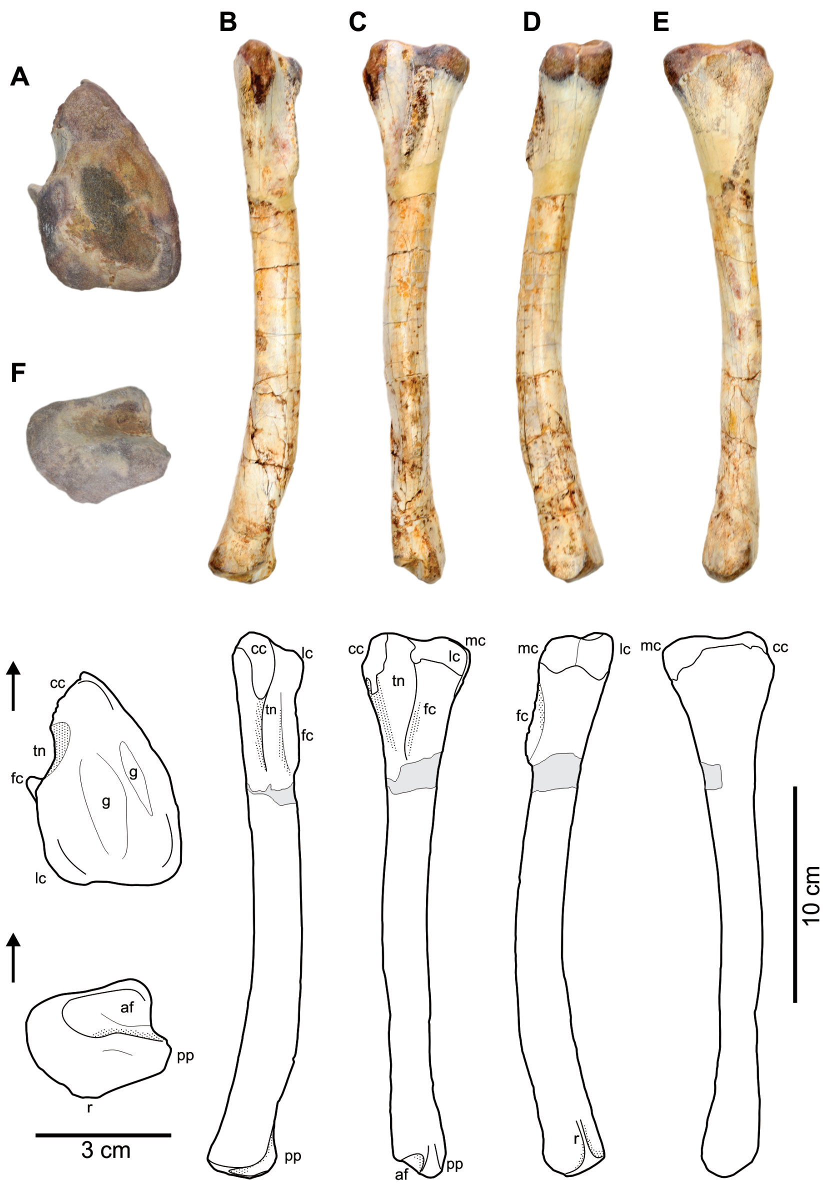

Figure 11A–F. Dockum neotheropod, right tibia, TTU-P10534. **A.** Tibia in proximal view. **B.** Anterior view. **C.** Lateral view. **D.** Posterior view. **E.** Medial view. **F.** Distal view. Abbreviations: **af**, articular facet for astragalus; **cc**, cnemial crest; **g**, groove; **lc**, lateral condyle; **mc**, medial condyle; **pp**, posterior process; **r**, posterior ridge; **tn**, tibial notch. Proximal and distal views share the 3 cm. scale bar. Hatching indicates the damaged areas; portions in grey represent cellulose sculpting medium. Arrow indicates anterior side for the proximal (**A**) and distal (**F**) views.

conditions, where some cracks and compression marks are visible, especially at the distal part displaying damage. The distal end is rhomboidal/sub-rectangular in distal view, possesses an enlarged posterior process (i.e., a post-fibular wing), a deeply penetrated articulation groove for the ascending process of the astragalus. A robust longitudinal ridge is also present on the distal margin of the posterior side (Fig. 11F).

This specimen was first mentioned in an abstract, then introduced elsewhere as "TTUP unnumbered" and referred to an undetermined theropod in the same work (Cunningham et al. 2002, Nesbitt et al. 2007). Complementing this preliminary identification, the distal articular surface pattern, a robust fibular crest and a longitudinal ridge on the posterior side of the distal end indicates TTU-P10534 represents a neotheropod (Rauhut 2003: character 208; Nesbitt 2011: characters 331, 336). Despite being almost half the size, the tibial morphology of TTU-P10534 closely resembles that of *Dilophosaurus wetherilli* Welles, 1984 (also see Rauhut 2003, text-fig. 45B), in particular the robust and poorly flared cnemial crest, slightly elevated medial border of the proximal surface, relative sizes of tibial condyles, the triangular fibular crest and the shape of the distal articular surface.

TTU-P14786—This specimen is the distal end of a left tibia. Although this is the only portion preserved, a deeply

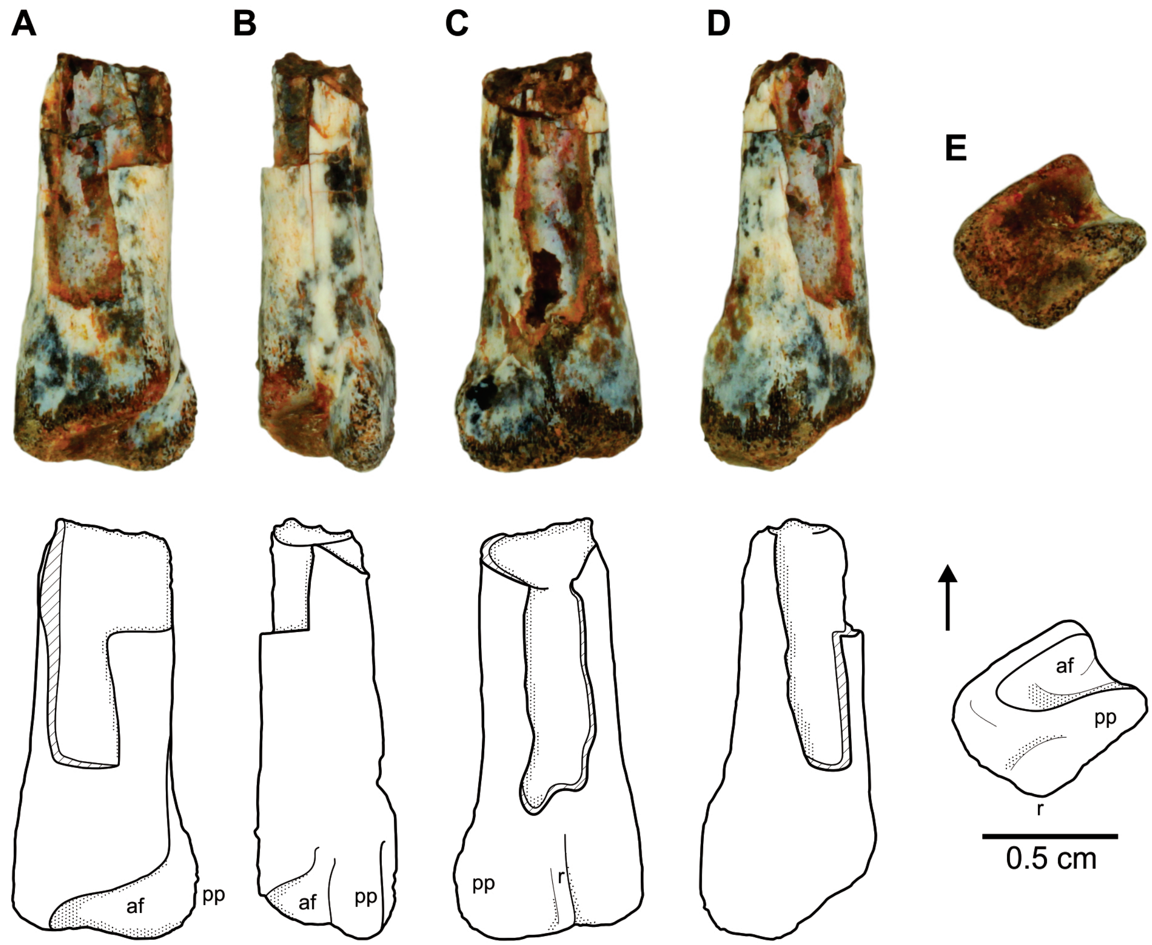

Figure 12A–E. Dockum neotheropod, distal portion of left tibia, TTU-P14786. **A.** Partial tibia in anterior view. **B.** Lateral view. **C.** Posterior view. **D.** Medial view. **E.** Distal view. Abbreviations: **af**, articular facet; **pp**, posterior process; **r**, posterior ridge. Proximal and distal views share the 1 cm. scale bar. Hatching indicates the damaged areas. Arrow indicates anterior side for the distal (**E**) view.

penetrated articulation facet on the rhomboidal distal surface for the ascending process of the astragalus, an enlarged posterior process on the lateral side, and a characteristic longitudinal ridge on the posterior side strongly support the neotheropod affinity of this specimen (Fig. 12A–E), as explained for TTU-P10534 above. The morphology of TTU-P14786 is similar to the distal section of TTU-P11044, a larger neotheropod tibia described from the Post Quarry (Nesbitt and Chatterjee 2008, Martz et al. 2013).

DISCUSSION AND CONCLUSIONS

Despite such prolific theropod diversity documented in the Upper Triassic Dockum Group, no ornithischian or sauropodomorph fossils are confirmed so far. Among the taxa that were previously described as ornithischians, *Technosaurus smalli* Chatterjee, 1984 is now reassigned as a silesaurid based on similar jaw and dental morphology (e.g., Nesbitt et al. 2007, Martz et al. 2013) and *Revueltosaurus callenderi* Hunt, 1989 is now considered to be a pseudosuchian possibly related to aetosaurs, after the discovery of the postcranial skeleton and skull (Parker et al. 2005, Nesbitt 2011). On the other hand, *Tecovasaurus murryi* Hunt and Lucas, 1994, *Lucianosaurus wildi* Hunt and Lucas, 1994, *Protecovasaurus lucasi* Heckert, 2004 and *Crosbysaurus harrisae* Heckert, 2004 are all diagnosed solely on isolated teeth as ornithischians (Hunt and Lucas 1994, Hunt et al. 1998, Heckert 2004); however, the described dental morphology appears to be homoplastic among archosauriforms, and the phylogenetic placement of these taxa remains uncertain (Irmis et al. 2007a). Moreover, reported prosauropod body fossils (e.g., Hunt et al. 1998, Harris et al. 2002) are too incomplete to be assigned to this clade with certainty (Nesbitt et al. 2007).

Presently, the Dockum dinosaur fauna consists solely of theropods (Nesbitt et al. 2007). In contrast, the Dockum Group of New Mexico has produced few confirmed dinosaur fossils (*contra* Hunt 2001). One of them is *Chindesaurus bryansmalli* to which a proximal end of a left femur and some vertebrae were referred (Long and Murry 1995, p. 174). There are two additional fragmentary skeletons; one of them is *Gojirasaurus quayi* Carpenter, 1997, which possibly represents another member of Coelophysoidea (Rauhut 2003, Nesbitt et al. 2007), and the other is an incomplete skeleton (NMMNH P-4569) that belongs to an indeterminate saurischian that was originally diagnosed as a theropod (e.g., Hunt 1994, Hunt 2001, Nesbitt et al. 2007).

A Historical Overview of the Dockum Theropod Fauna of Texas, USA

The history of fossil discoveries in the Dockum Group of Texas spans more than a century and many specimens have been referred to theropods since the earliest years. Some isolated teeth collected by William Fletcher Cummins (1840–1931), who first coined the name Dockum in 1889 for the Triassic red beds of Texas (Cummins 1890), represent the earliest fossils attributed to theropods from this region. The teeth collected by Cummins were assigned to three taxa in 1893 by Edward Drinker Cope (1840–1897) as an unnamed species of *Clepsysaurus* Lea, 1851, *Palaeoctonus orthodon* Cope, 1893 and *P. dumblianus* Cope, 1893. More specimens were published by Ermine Cowles Case (1871–1953) during the first half of the 20th century. First, a series of presacral vertebrae with relatively long neural spines (UMMP 7507), a partial braincase (UMMP 7473) and a left femur (UMMP 3396) were reported from Crosby County (Case 1922). Subsequently, an isolated right ilium (UMMP 8870), few undetermined vertebrae (UMMP 7277), some caudal vertebrae (UMMP 9805) and various compressed, recurved teeth (e.g., UMMP 2680) were added to the Dockum fossil record from the same county (Case 1927). All of the mentioned specimens were assigned to *Coelophysis* Cope, 1889, one of the earliest described dinosaurs and an iconic taxon of the American Southwest, or to a closely related "coelurosaurid" taxon by Case himself. In 1932, discovery of a series of associated caudal vertebrae (UMMP 13670) and several isolated teeth (e.g., UMMP 13765 and UMMP 13766) from Potter County were also attributed to *Coelophysis* (Case 1932). In the same year, Friedrich von Huene (1875–1969) proposed a new theropod taxon, *Spinosuchus caseanus* von Huene, 1932, based on the vertebral column (UMMP 7507) and the partial braincase (UMMP 7473) that were first introduced by Case in 1922. Furthermore, the caudal vertebrae and teeth described by Case in 1927 were also referred to this taxon by von Huene. In contrast, von Huene declared that the rest of the skeletal elements collected by Case could not be attributed to *Coelophysis*, whereas some elements were ascribed to parasuchids, including UMMP 8870. More specimens were referred to *Coelophysis* from various other Texas Panhandle localities in Howard, Borden, Crosby, Randall, and Potter counties by Joseph T. Gregory (1914–2007) and Ruth L. Elder (1954–2014) during the 20th century (e.g., Gregory 1945, 1972, Elder 1978, 1987), including the Otis Chalk quarries where digging was started by the Works Progress Administration project during the late 1930s (Fig. 1).

The dinosaur affinity of all of these specimens has been recently questioned in a series of comprehensive re-evaluations and the results demonstrate quite a different picture. The three taxa described by Cope (1893) based on dental remains are now considered phytosaurs *nomia dubia* (e.g., Stocker and Butler 2013). Following the assignment of the partial braincase (UMMP 7473) to *Postosuchus kirkpatricki* (Chatterjee 1985), the holotype of *Spinosuchus caseanus* was restricted to the vertebral column (UMMP 7507) and the taxonomic status of this taxon remained as *nomen dubium* for long time (Padian 1986, Murry 1986, Long and Murry 1995, Murry and Long 1997). The vertebral column was initially referred to an undetermined archosauriform (Nesbitt et al. 2007), but recent works conclude that *S. caseanus* is a trilophosaurid (Spielmann et al. 2009, Nesbitt et al. 2015). Moreover, the ilium (UMMP 8870) identified by Case (1927) was first attributed to an indeterminate herrerasaurid (Murry 1986, 1989), then assigned to *Chindesaurus bryansmalli* together with the proximal extremity of a left femur (TMM 31100-523) from the Otis Chalk Quarry 3 (Long and Murry 1995, also see Langer 2004). Shortly afterwards, UMMP 8870 was designated as a holotype of a new taxon *Caseosaurus crosbyensis* Hunt et al., 1998, and TMM 31100-523 was referred to an undetermined dinosaur (Hunt et al. 1998). Although UMMP 8870 has some characters in common with the basal theropods, the taxonomic placement of this element is still uncertain, but TMM 31100-523 remains assignable to *C. bryansmalli* (Nesbitt et al. 2007, Nesbitt and Chatterjee 2008).

On the other hand, the caudal vertebrae described by Case in 1932 appear to represent a rauisuchid (Murry and Long 1997), whereas the teeth introduced in the same work do not offer any diagnostic features to pinpoint a taxon more inclusive than Archosauria (Hunt et al. 1998). Finally, the dinosaur affinities of the specimens introduced by J. T. Gregory and R. D. Elder remain unconfirmed (Murry and Long 1997). The taxonomic status of *Protoavis texensis*, another alleged theropod from the Dockum Group of Texas, is not yet resolved (e.g., Ostrom 1991, Chiappe 1995, Padian and Chiappe 1998, Nesbitt et al. 2007, Martz et al. 2013). This taxon is excluded from the present study because of its controversial status.

Additionally, re-appraisal of some taxa, which were originally referred to Dinosauria, reveals that they are actually pseudosuchians. The pseudosuchians *Poposaurus gracilis* Mehl, 1915 (UMMP 11748, Colbert 1961) and *Shuvosaurus* *inexpectatus* Chatterjee, 1993 were once treated as theropods, where *Postosuchus kirkpatricki* was initially described as a carnivorous thecodont, which might have given rise to tyrannosaurs (Chatterjee 1985). A cladistic approach reveals a clear split between pseudosuchian and dinosaurian lineages (e.g., Gauthier 1986, Benton and Clark 1988, Sereno 1991, Long and Murry 1995, Nesbitt and Norell 2006) and the establishment of this new method resulted in elimination of the former from the Dockum theropod fauna.

Current status of the Dockum theropod fauna

None of the reported specimens in the early works mentioned above belong to a theropod, except a proximal fragment of a femur (TMM 31100-523) and possibly a right ilium (UMMP 8870) (Fig. 3). In contrast, almost all of the verified theropod specimens from the Upper Triassic Dockum Group of Texas were collected in the last 40 years. The bulk of unequivocal theropod elements were collected by Sankar Chatterjee and his crew from the Museum of Texas Tech University, as part of current and ongoing studies of the Dockum terrestrial tetrapod fauna in Texas that started in the 1980s (e.g., Chatterjee 1986, Lehman and Chatterjee 2005). Despite these specimens originally being referred to *Coelophysis*, taxonomic reassessment of the collected material (TTU-P10071, TTU-P10072, TTU-P10082, TTU-P10534 and TTU-P11044) indicates the presence of basal theropods (e.g., herrerasaurids) and neotheropods (Nesbitt et al. 2007, Nesbitt and Chatterjee 2008, Martz et al. 2013, also see above) (Fig. 3). The recent discoveries of *Lepidus praecisio* (holotype TMM 41936-1.3 and paratypes TMM 41936-1, TMM 41936-1.1), a new neotheropod from near the distinct landform named Signal Peak, which is also close to the Otis Chalk quarries, and a few isolated limb bones such as a femur (TTM 31100-545) and a tibia (TMM 31100-1324) from the Otis Chalk Quarry 3 (MOTT 2000), complement the previously described specimens (Stocker 2013, Nesbitt and Ezcurra 2015) (Fig. 3).

Dockum theropod diversity in Texas now includes more theropod specimens with the majority belonging to basal theropods (TTU-P11175, TTU-P12531X, TTU-P12587X, TTU-P16789) and a new neotheropod specimen (TTU-P14786) (Fig. 3). Collected from multiple quarries at different stratigraphic horizons, the specimens increase the relative abundance of theropods in the Dockum Group. Morphological disparity of the Dockum theropods differ from tiny and gracile limb elements with shaft diameters of about one centimeter (e.g., TTU-P12587X, TTU-P14786) to much larger specimens (e.g., TTU-P10082, TTU-P10534). The up-section extension of the biostratigraphic ranges of Dockum theropods demonstrates that the basal theropods and neotheropods coexisted during the entire Late Triassic, at least in western Texas (see also Irmis et al. 2007b). However, the fragmentary condition of the specimens prevent a more definitive taxonomic designation to genus and/or species in most cases, and thus, are not currently very useful for faunal correlation. Nevertheless, future studies of dinosaurs in the Late Triassic tetrapod terrestrial fauna appear promising, as the potential is high for the finding of new more complete theropod (or even ornithischian and sauropodomorph) fossils in the Dockum Group.

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