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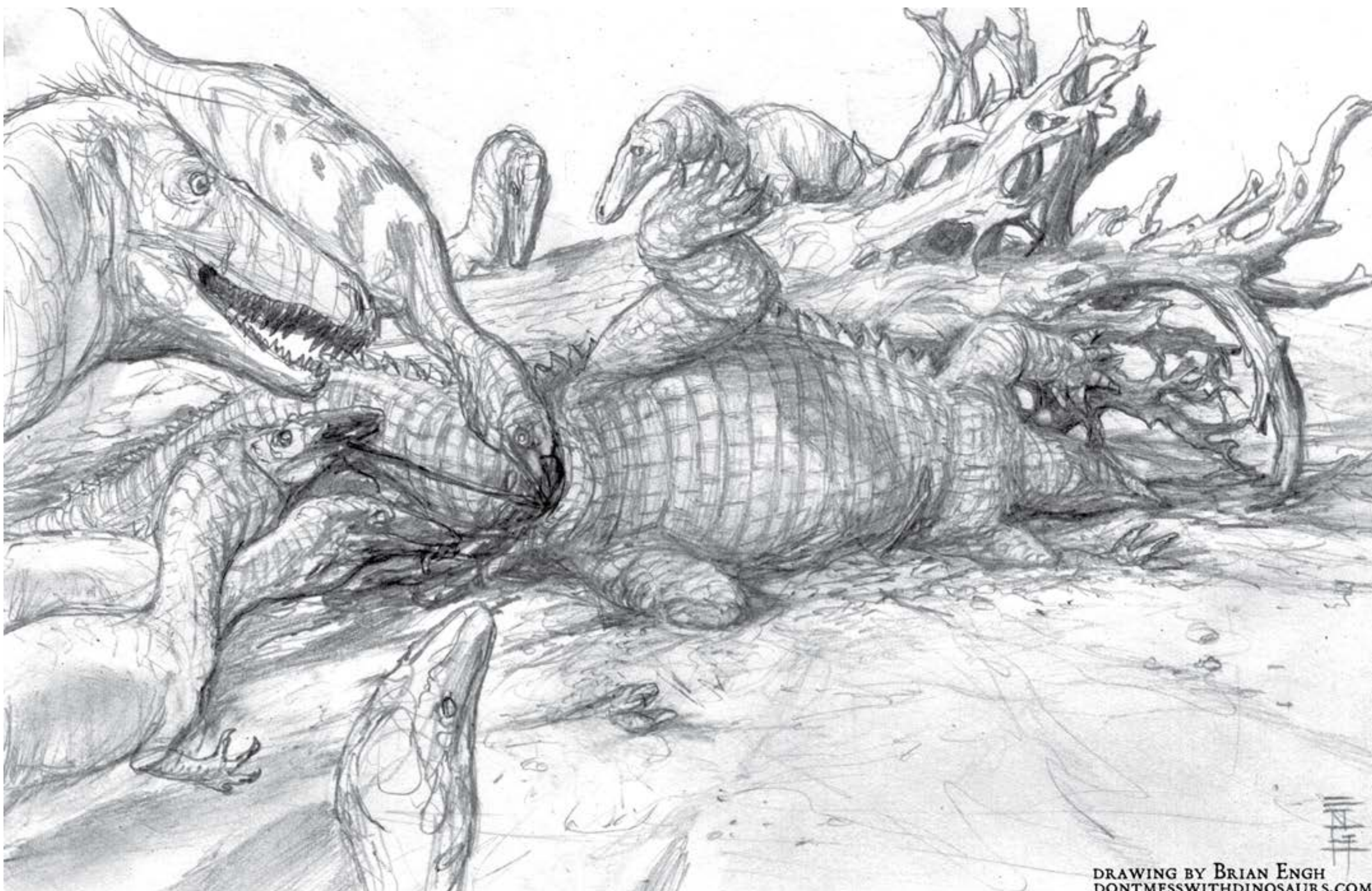

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Cover
Depiction of neotheropods eating an aetosaur. Artwork by Brian Engh, dontmesswithdinosaurs.com.

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First Unambiguous Dinosaur Specimen from the Upper Triassic Chinle Formation in Utah

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ABSTRACT

Triassic dinosaurs represent relatively rare but important components of terrestrial faunas across Pangea. Whereas this record has been well studied at various locales across the American West, there has been no previous systematic review of Triassic material assigned to Dinosauria from Utah. Here, we critically examine the published body fossil and footprint record of Triassic dinosaurs from Utah and revise their record from the state. In addition, we describe a sacrum from a locality within the Upper Triassic Chinle Formation of southeastern Utah. This specimen represents the only unambiguous Triassic dinosaur body fossil from Utah. MWC 5627 falls within the range of variation known for sacrum morphology from *Coelophysis bauri*. Based on a literature review and examination of specimens available to us, we restrict the Triassic Utah dinosaurian record to Theropoda from the Chinle Formation. Preliminary reports of Triassic dinosaurs from other clades and formations in Utah are unsubstantiated.

INTRODUCTION

Theropod dinosaurs are an important but rare component in terrestrial faunas from the Triassic of western North America (Nesbitt and others, 2007). Although several taxa have been identified from New Mexico, including *Coelophysis bauri* (Colbert, 1989; Rinehart and others, 2009), *Gojirasaurus quayi* (Carpenter, 1997), *Chindesaurus bryansmalli* (Irmis and others, 2007), *Tawa hallae* (Nesbitt and others, 2009), and *Daemonosaurus chauliodus* (Sues and others, 2011), the surrounding continental deposits have produced little in the way of dinosaurian body fossils. In contrast, an apomorphy-based study by Nesbitt and others (2007) examined all referred dinosaurs from the Triassic of western North America and found only *Caseosaurus crosbyensis* (Long and Murry, 1995) present in Texas. The same study found only two theropods, *C. bryansmalli* (Long and Murry, 1995) and a coelophysoid (Padian, 1986) from Arizona. Nesbitt and others (2007) did not find references to Triassic theropods in Colorado and Utah. Unfortunately, that review did not assess reported dinosaurian remains from the Four Aces mine locality near the Glen Canyon National Recreation Area in southeastern Utah (Parrish, 1999) (figure 1). In a related study, Irmis and others (2007) found reports that described ornithischian dinosaurs from the Triassic of North America had been misinterpreted, although this study also overlooked the Parrish (1999) report from southeastern Utah.

Various methods have been proposed to explain the distribution of dinosaurs in North America. The

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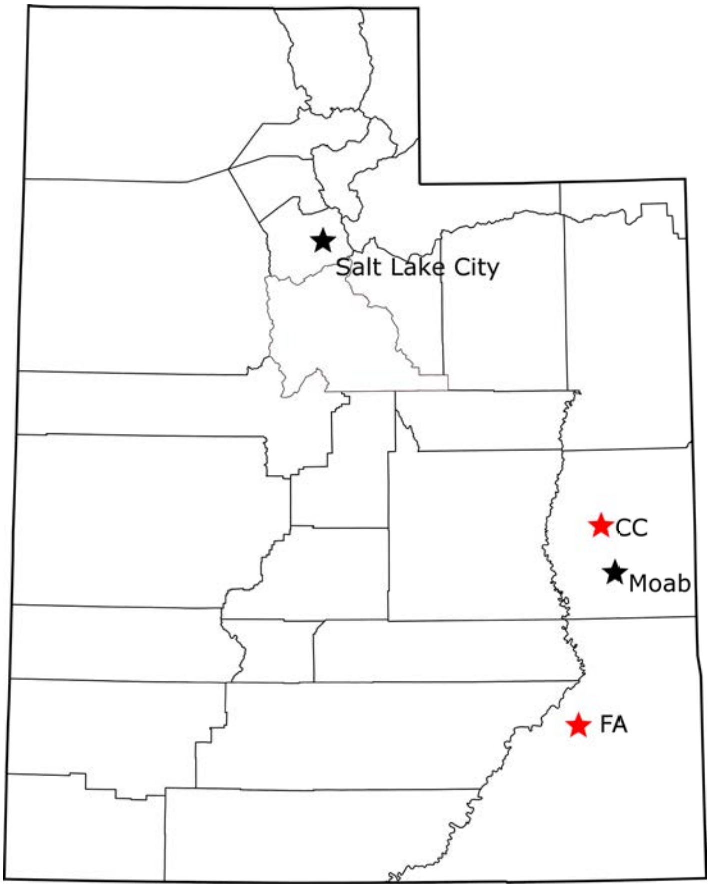

Figure 1. Map of Utah's Triassic dinosaur occurrences. CC = Corral Canyon, FA = Four Aces.

current consensus is that the radiation of Dinosauria across the globe was diachronous (Nesbitt and others, 2009; Irmis and others, 2011; Kent and others, 2014; see Ramezani and others, 2011, for a dissenting view). The earliest records of all major dinosaurian clades came from southern Pangaea in the Carnian Stage of the Late Triassic Epoch, followed by later appearances in the Norian and Rhaetian Stages in the north of the supercontinent (Rauhut and Hungerbühler, 2000; Parker and Martz, 2011). Dinosaur body fossil remains from Utah may help test some of these timelines and hypotheses by providing additional data on dinosaur distribution and the timing of this distribution.

Utah and western Colorado have a rich record of vertebrate trace fossils from their Triassic rocks, including many localities preserving *Grallator*, an ichnotaxon traditionally identified as pertaining to theropod dinosaurs (Riggs, 1904; Bunker, 1957; Parrish and Lockley, 1984; Hamblin and Foster, 2000; Foster and others, 2001; Gaston and others, 2003; Santucci and others, 2006; Hunt and Lucas, 2007; Martz and others, 2014), and some preserving the purported prosauropod track *Pseudotetrasauropus* (Lockley and Hunt, 1995; Foster and others, 2001). Recent work by other authors has raised questions about the reliability of identifying dinosaurs from ichnological evidence alone (Olsen and others, 1998; Marsicano and others, 2007; Brusatte and others, 2011; Niedźwiedzki, and others, 2013; Farlow and others, 2014). Although a poposauroid footprint reconstruction based on an articulated specimen of *Poposaurus gracilis* from the Circle Cliffs of southern Utah (Farlow and others, 2014) is somewhat similar to *Grallator*, it is only so if the first digit never impressed. There are a number of *Grallator* specimens from the Chinle Formation in Utah and western Colorado that look rather different at least from hypothetical tracks of poposauroids, and the fact that the ichnogenus continues upward through the Wingate, Kayenta, and Navajo Formations (by which time poposauroids and other convergent non-dinosaurs were extinct) suggests that many tracks assigned to *Grallator* (though not necessarily all) were likely made by theropods. The dinosaurian affinity of *Pseudotetrasauropus* is perhaps a bit more tenuous, as the morphology of these tracks can overlap to some degree with those of several other tetradactyl ichnogenera attributed to non-dinosaurian archosaurs known from the Late Triassic (Lucas and Heckert, 2000). Thus, the ichnological evidence for the presence of dinosaurs in what is now the state of Utah during the Triassic Period is to some degree ambiguous. There may likely be many dinosaurian tracks among the specimens assigned to *Grallator* and *Pseudotetrasauropus*, but it is possible that some non-dinosaurian archosaurs made at least some of the tracks historically assigned to these ichnogenera from various localities, and distinguishing these will require more studies of non-dinosaurian taxa (e.g., Farlow and others, 2014).

Since 2005, several discoveries have taken place in early Mesozoic strata across the western United States that require us to revisit the Triassic record of Dinosauria from the state of Utah. Other workers have reported on the presence of well-preserved coelophysoid skeletons (Chambers and others, 2011; Britt and others, 2016) from the Nugget Sandstone in Dinosaur National Monument. Traditionally described as being Early Jurassic in age, the Nugget has been attributed in later reports as being from the Late Triassic (Sprinkel and others, 2011; Engelmann and others, 2012; Britt and others, 2015, 2016; Irmis and others, 2015). Although these specimens have not been formally described yet, we think the initial evidence, which remains unpublished but as been presented in poster and talk format previously, matches with a Triassic age (Shumway and others, 2016). Additionally, a site near Moab, Utah, has yielded new remains that we refer here to theropod dinosaurs. The specimen described here has come from the Chinle Formation and is thus unequivocally Late Triassic (Norian-Rhaetian) in age (Martz and others, 2014 and references therein).

The purpose of the paper is to critically examine the published record of Utah's Triassic dinosaur fossils and to determine whether previously described body fossils can confidently be assigned to Dinosauria based upon an apomorphic evaluation. Additionally, we describe the first unambiguous dinosaur body fossil from the Triassic of Utah using an apomorphic framework.

INSTITUTIONAL ABBREVIATIONS

AMNH – American Museum of Natural History, New York (USA); **CLMNH –** Cleveland Museum of Natural History, Cleveland, Ohio (USA); **GR –** Ghost Ranch Ruth Hall Museum of Paleontology, Ghost Ranch, New Mexico (USA); **MNA –** Museum of Northern Arizona, Flagstaff, Arizona (USA); **MWC –** Museums of Western Colorado, Fruita, Colorado (USA); **NMMNH –** New Mexico Museum of Natural History and Science, Albuquerque, New Mexico (USA); **NMW –** Amgueddfa Cymru-National Museum Wales; **PVSJ –** Instituto y Museo de Ciencias Naturales, San Juan (Argentina); **TMP –** Royal Tyrrell Museum, Drumheller, Alberta (Canada); **UCM –** University of Colorado Museum, Boulder, Colorado (USA).

STUDY METHODS

John Foster and Ray Bley collected the sacrum (MWC 5627) in 2005, with locality data being on file at the MWC's Dinosaur Journey repository under Bureau of Land Management (BLM) permit UT-S-05-014. The sacrum (MWC 5627) was collected from a boulder-size block of conglomerate that had fallen off the outcrop from a bed at the base of the Church Rock Member. The sacrum was found in a small piece (less than than 25 cm) of conglomerate chiseled from the larger, fallen block as part of the standard field procedure for prospecting at this locality.

Specimen MWC 5627 was prepared over the years by various volunteers at MWC, where it had been damaged as the surrounding matrix was being removed. John Foster and Robert Gay studied MWC 5627 in person. Measurements were taken on the specimens using Craftsman model 40257 sliding metal calipers (precision = 0.05 mm). Standard paleontological tools (dental tools, ice picks, and natural-bristle brushes) were used to collect all specimens.

Some of the comparisons between the specimens described here and other taxa were made using in-person examination of original specimens and casts; specifically for *Coelophysis bauri*. For other taxa, relevant measurements were taken from the published scientific record. Photographs for figures were taken using a Nikon D5100. Computer tomography (CT) images of MWC 5627 were obtained at the Family Health West hospital in Fruita, Colorado, on February 11, 2016, using an Optima CT scanner. Specific Kv values are reported in figures obtained from CT imaging. CT data were digitally prepared using InVesalius 3.0 (64-bit) to create the three-dimensional (3D) digital model of MWC 5627 using a 2186-3071 mask to initially isolate the bones in the digital matrix, then using fine selection and deletion tools to remove high-density matrix returns from the CT data. SedLog was used to make the stratigraphic column and U.S. Geological Survey lithological patterns were used. All figures were created in GIMP 2.8.16.

LOCALITIES AND GEOLOGICAL SETTING

The Corral Canyon locality is north of Moab, Utah (figure 1). There, the Chinle Formation consists of the lower Kane Springs beds of Blakey and Gubitosa (1983, 1984; Martz and others, 2014, 2017) and the upper Church Rock Member (Stewart and others, 1972; Matrtz and others, 2014, 2017) (figure 2). The bed, from where

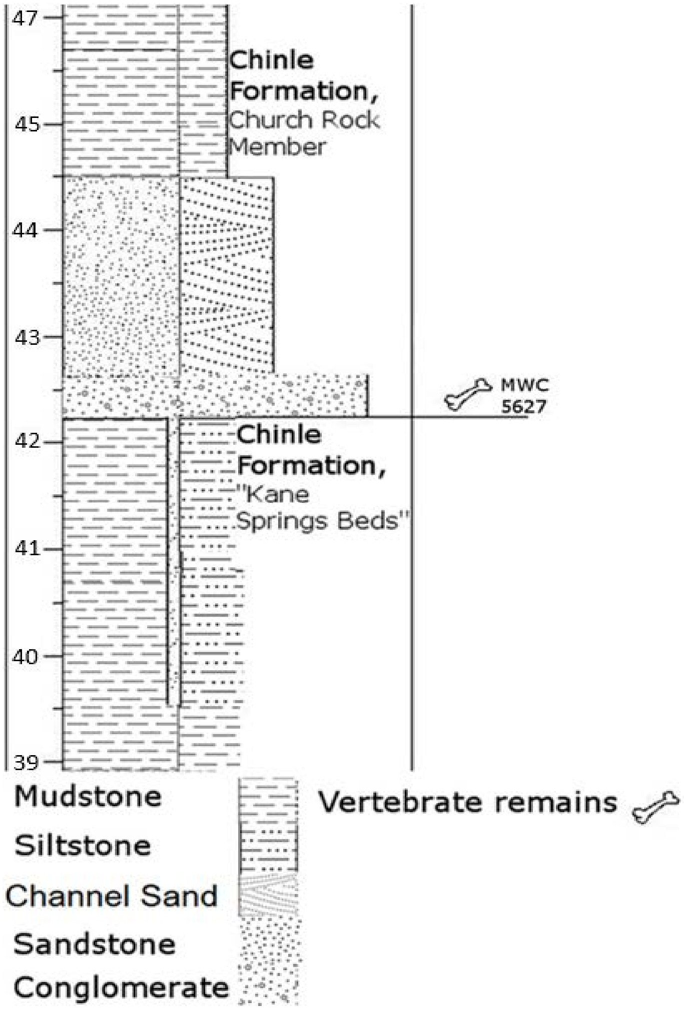

Figure 2. Partial stratigraphic column of the Corral Canyon locality, showing the location of MWC 5627 in relation to stratigraphic position. See key for sedimentological symbol details. Scale in meters. The complete stratigraphic column is attached and can be view by clicking here.

block containing the sacrum (MWC 5627) broke off, is at the base of the Church Rock Member in the lower half of the 106-m-thick Chinle section; approximately 43 m above the Moenkopi-Chinle contact and 63 m below the Wingate Sandstone (figure 2). There are three conglomerate beds in the Chinle Formation at Corral Canyon (from ~3 m above the base of the formation to ~18 m below the top), at least two of which were observed to contain numerous teeth and bone fragments of mostly phytosaurs. The Chinle in the Corral Canyon area also contains abundant permineralized wood; archosaur tracks are found in relative abundance near the top of the formation near the contact with the Wingate Sandstone (personal observations of John Foster and Robert Gay). To protect the locality of the sacrum, a stratigraphic section of the Chinle Formation from the general area is used here to illustrate the stratigraphy of the Chinle in Corral Canyon (figure 3), although this section is thinned in comparison to the specimen's section.

SYSTEMATIC PALEONTOLOGY

Dinosauria Owen, 1842; sensu Baron and other, 2017
Ornithoscelida Baron and others, 2017
Theropoda Marsh, 1881
Neotheropoda Bakker, 1986; sensu Hendrickx and others, 2015

Referred Specimen: MWC 5627, sacrum consisting of two primordial sacrals, one inserted sacral, a dorsosacral, and a caudosacral as well as fragmentary neural arches.

Specimen MWC 5627 is a partial sacrum preserved in a 30-cm-size block of conglomerate (figure 4). The pebble to cobble conglomerate is comprised of well-cemented, sandstone matrix with chert and clay clasts. Clast size ranges from 1 to 5 cm. The sacrum consists of three well-preserved complete and two partial, less-well-preserved, sacral vertebrae, exposed on their ventral and right lateral side. They contain impressions of some of the vertebrae, along with some minor bone fragments that do not provide any additional information about the sacrum itself. Utilizing the CT data obtained, we digitally prepared MWC 5627 to attempt to better visualize the portion of the sacrum still within the matrix, although the dense nature of the matrix and the low power of the medical scanner, the resolution of the CT images were not high. These data were informative and are included as supplementary online materials.

Sacral vertebra 1 (SV1) is poorly preserved, although when first discovered it was much more complete. Collection damage, along with some preparation damage, have made interpretation of this element difficult. Partial fusion between sacral vertebra 2 (SV2) and SV1 can be seen at two locations where SV1 remain; along the left dorsolateral surface and again at the dorsal surface

Figure 3. Section of the Chinle Formation near Corral Canyon, Grand County, Utah, looking west. Formation contacts are solid yellow lines; Chinle members contact dashed. Two lower arrows mark two of three conglomeratic beds in Chinle; upper arrow with question mark shows approximate laterally equivalent level of top conglomeratic bed in Corral Canyon. Although this is not the section from where the sacrum was collected, the red circle marks approximate stratigraphic position of MWC 5627 near base of middle conglomerate. Scale bar = 12 m.

at the neural canal. The neural spine is likewise mostly gone, possibly due to preparation damage. Despite the damage, the centrum of SV1 is clearly hollow (figure 4).

SV2 is the first completely preserved vertebra in the sacral series. It is fused to the sacral vertebra posterior to it. It is incompletely fused to the sacral vertebra 3 (SV3). The anterodorsal gap is 8 mm antero-posteriorly and 5 mm dorsoventrally, making it roughly ovoid in shape. Of the four gaps found in MWC 5627 this is the best preserved. Its relationship to the sheet of bone forming the lateral surface of the SV2/SV3 neural spines and sacral ribs is clear. It lies 4.5 mm posterior to the attachment of the SV2 sacral rib and 6 mm of fused neural spine are above its dorsal-most point. Its posterior-most point is 1 cm anterior to the attachment of the SV3 sacral rib. SV2 itself is cracked and repaired, hollow, and has an overall broader appearance than the preceding sacral vertebrae.

SV3 is completely fused on the exterior of its articular surfaces to both SV2 and sacral vertebra 4 (SV4). The posterior gap above the centrum is 7.5 mm in length antero-posteriorly. A clear portion of bone is visible dorsal to the centrum, representing part of the neural spine, though it is not well defined in the CT data (online supplementary data). SV3 is broken along the right lateral surface, showing some of the hollow interior of the centrum. The centrum being hollow is further supported by the CT data.

SV4 is the largest and best preserved of the sacral vertebrae. It is 2.6 cm in length antero-posteriorly, as measured between the points of fusion along the articular surface on the right lateral surface. On the exposed

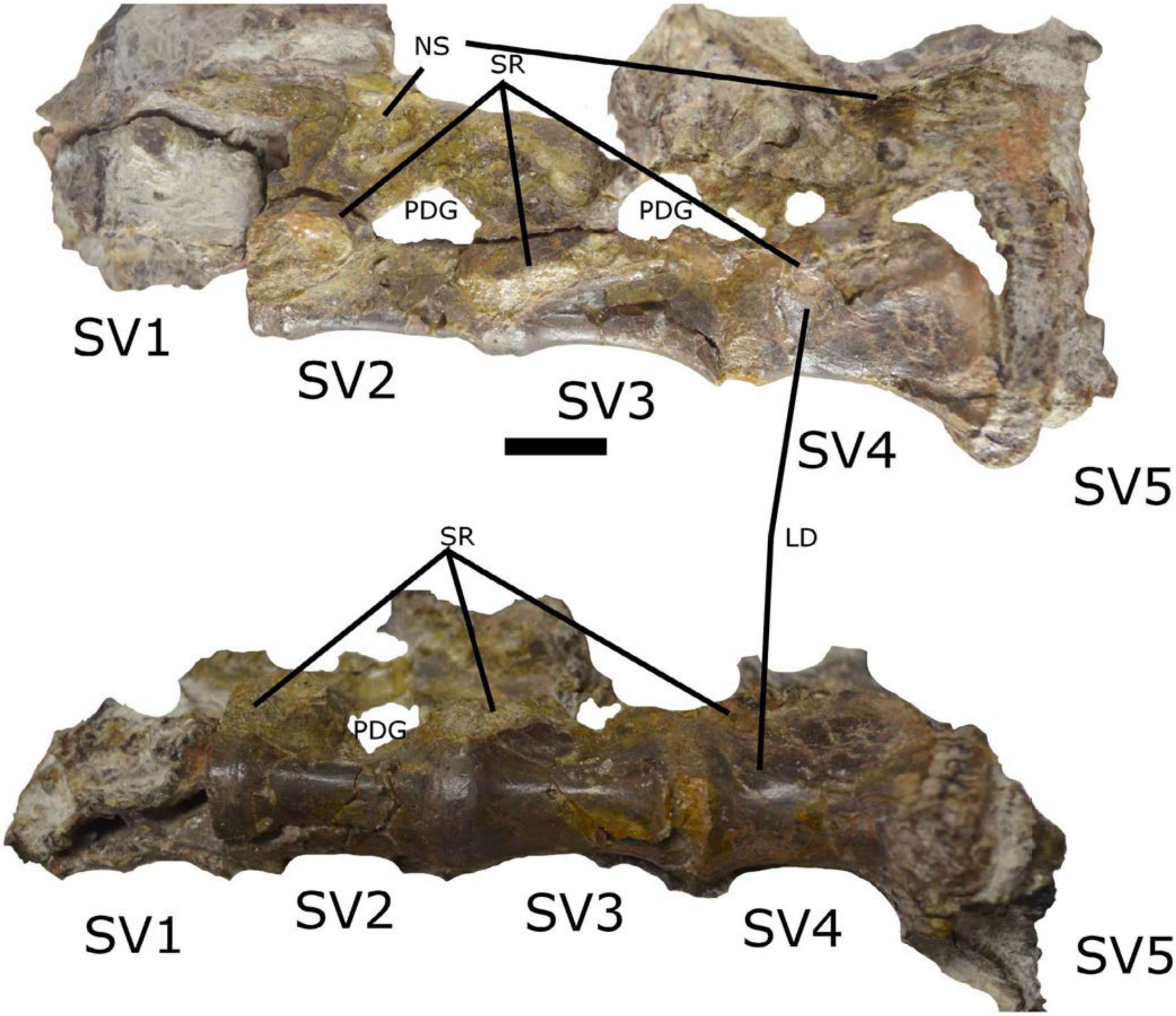

Figure 4. MWC 5627 in left lateral and ventral views. LD = lateral depression; NS = neural spine; PDG = posterior dorsal gap; SR = sacral ribs; SV = sacral vertebrae. Scale bar = 1 cm.

lateral surface, 5 mm posterior from the anterior articular surface and just ventral to the dorsal margin, there is a slight depression on the centrum. This depression is 9 mm in length and 1 mm in depth at its deepest point. Between the posterior articular surface and the attachment of the sacral rib, dorsal to the centrum, there is an 8.5-mm-long break or gap allowing access to the neural canal. This has also been infilled with matrix, but can be clearly seen with both visual (figure 4) and CT imaging. The tallest portion of the neural spine does not show up in the CT data. The posterior articular surface is well fused around the rim, though CT data shows there to be some unfused portion within the center of the articulation, as between SV1/SV2 (figure 4). The anterior articular surface is 1.4 cm mediolaterally, as measured at the dorsoventral midpoint, and 1.3 cm dorsoventrally, as measured at the center of fusion between SV4 and SV3.

Sacral vertebra 5 (SV5) is the worst preserved vertebra in the sacrum. SV5 is present as an anterior articular surface in articulation with the adjoining sacral vertebrae. The articular surface is fused to SV4 around the rim of the articular surface, but exhibits incomplete fusion within the midpoint of this same surface. This is visible in both examinations of the specimen itself as well as in CT images of MWC 5627 (figure 4, online supplementary data). The preserved portion of the centrum is broken in several places, with the hollows infilled with a sand/clay matrix. The remains of the sacral rib and neural spine are fused to those of SV4.

Overall the centra of MWC 5627 tend to be shallow ventrally with progressively narrowing midcentra posteriorly. The neural arches are broad and become complex towards the caudal portion of the sacrum (though this may be a product of preservation). The sacral rib attachments arise from the anterior portion of the centrum and posterior-most section of the preceding sacrum, almost obscuring the articular surface, especially moving posteriorly. The preserved sacral ribs are antero-posteriorly elongate and laterally significant (1.2 cm across for the sacral rib on SV4).

As mentioned above, some of the anatomical features on the surface of the fossil, specifically the thin bony struts of the neural spines and sacral ribs, are not well resolved in the CT data. Whereas the CT data do indicate that SV2–SV4 are relatively complete within the matrix, the adjoining neural spines and ribs are not likewise present. Because of the fact that portions of these elements have been damaged during past physical preparation and that these elements are not visible in CT image; we have refrained from further physical preparation of MWC 5627 to avoid additional damage or loss of data.

TAXONOMIC AFFINITIES

Possessing five sacral vertebrae is generally considered a synapomorphy for Neotheropoda (Padian and others, 1999; Sereno, 1999a, 1999b), though it is known that some basal ornithischians possess at least four and possibly five sacral vertebrae, as in the case of *Eocursor parvus* (Butler and others, 2007), and with *Heterodontosaurus* having six (Sereno, 2012). Additionally, other archosaurs occasionally have four sacrals and a dorsosacral (Nesbitt and others, 2007; Nesbitt 2011). Considering this, we restrict our comparisons to taxa with similar sacral vertebrae counts, but offer some brief commentary on some taxa that still warrant consideration.

Coelophysis bauri is the most common Late Triassic dinosaur from North America. It has been described from New Mexico (Colbert, 1989; Schwartz and Gillette, 1994; Rinehart and others, 2009). Having one of the largest sample sizes of all theropod dinosaurs from the Mesozoic Era allows us to use a broad morphological dataset to compare against MWC 5627.

Coelophysis bauri specimens AMNH 7228, AMNH 7229, AMNH 7245, CLMNH 10971-D2, NMMNH P-42351, P-42353, and P-42580 (Rinehart and others, 2009) all exhibit a morphology similar to MWC 5627 in that their SV4 and SV5 are not fused, and AMNH 7233 exhibits only partial fusion of SV4 and SV 5. Specimens AMNH 7235, AMNH 7243, AMNH 7249, CLMNH 10971-D10, NMMNH P-44802, TMP 84-63-34, and TMP 84-63-49, again from Rinehart and others (2009), show SV4 and SV5 fully fused. This suggests that fusion in the sacrum of coelophysoid theropods is variable and that an unfused or partially fused SV4/SV5, as seen in MWC 5627, does not preclude it from pertaining to a coelophysoid. Coelophysoid sacral vertebrae are also ossified into a 'rod,' with the centrum being obliterated, as present in MWC 5627.

An additional coelophysoid sacrum (NMMNH P-31661) sheds light onto the affinities of MWC 5627. Illustrated by Nesbitt (2011, figure 29, p. 114), this sacrum shows the same broad, complex neural arches, shallow vertebral centra becoming dorsoventrally deep along the vertebral column, and high anteriorly situated attachments for the sacral ribs. MWC 5627 also shares with NMMNH 31661 several character states listed by Nesbitt (2011) which differentiate the two from more primitive archosauriforms, including the absence of sacral centra articular rims. Although not autapomorphic for the genus, these states are at least present in *Coelophysis*, for example. This contrasts with the other archosauriform sacra illustrated and described alongside NMMNH P-31661. Specimen MWC 5627 is also visibly identical to NMMNH 31661.

Although most Triassic archosaurs possess at least two sacral vertebrae, some members of the Poposauridae have four or more (Weinbaum and Hungerbuhler, 2007; Gauthier and others, 2011; Griffin and others, 2017). Although the published descriptions of *Poposaurus* sacra are severely limited, some comparisons are possible. In *Poposaurus*, the first sacral vertebra is roughly half the antero-posterior length of the third and fourth sacrals. The second sacral is roughly a third longer antero-posteriorally than the third or fourth sacral. In addition, only SV1-SV3 fuse, leaving SV4 unfused at the posterior end of the sacrum. This differs from the condition seen in MWC 5627, where at least four sacral vertebrae are fused with the fifth, the posterior-most being partially fused. Even if poposaurids exhibit differing levels of sacral fusion as does *C. bauri*, the comparative dimensions of the preserved vertebrae, seen most significantly in SV2 of MWC 5627 and *Poposaurus* specimen TMM-43683-1, rule out MWC 5627 as pertaining to poposaurids. Furthermore, the *Poposaurus* sacrum figured in Weinbaum and Hungerbuhler (2007), shows additional differences in sacral vertebra morphology, with *Poposaurus* sacral vertebrae being much more robust and with less mediolateral constriction in ventral view. *Shuvosaurus* and *Effigia* have four sacral vertebrae plus a dorsosacral (Nesbitt and others, 2007). In *Shuvosaurus, Effigia*, and in many theropods, the centrum has been obliterated, leaving the sacral vertebrae fused into a 'rod' (Nesbitt and others, 2007). This ossification is present in MWC 5627 and does not appear present in *Poposaurus* specimen YPM VP.057100.

Herrerasaurids are known from the Chinle Formation in Arizona and New Mexico, specifically the taxon *Chindesaurus bryansmalli* (Long and Murry, 1995; Nesbitt and others, 2007, 2009). We have ruled out herrerasaurids in our comparative analysis as herrerasaurids possess only two sacral vertebrae (Nesbitt and others, 2007). Similarly, *Eoraptor lunensis*, a Triassic sauropodomorph from South America (Sereno, 1999a), shows a reduced number of sacral vertebrae (3) and Nesbitt and others (2009) reported that *Tawa hallae* only possesses two sacrals. Like *E. lunensis*, *Eodromaeus murphi* only possessed three sacral vertebrae (Martinez and others, 2011). Although an actual number is not given for *Dracoraptor hanigani*, the published record shows a minimum of two and possibly up to three sacrals were present (Martill and others, 2016), with possibly more being unpreserved or described. *Silesaurus*, a dinosauriform (Dzik, 2003) has four sacral vertebrae. We, therefore, exclude all of these previously described basal theropods and dinosauriforms as pertaining to MWC 5627.

Although ornithischian dinosaurs are not currently recognized from the Triassic of North America (Irmis and others, 2007), it is possible that the sacrum of MWC 5627 could represent the first possible occurrence of this clade. The ornithischian dinosaur *Eocursor parvus* (Butler and others, 2007) is described as having at least four, and possibly five, sacral vertebrae; a character shared with MWC 5627. The sacral vertebrae are not preserved themselves, but instead are interpreted by the presence of neural arches lacking centra and sacral rib attachment scars. This makes direct comparisons between MWC 5627 and *E. parvus* impossible at this time.

Out of all the possible taxa that preserve sacral vertebrae from the Triassic of the western hemisphere, the only one that shares any number of significant morphological features (such as the number of sacral vertebrae, roughly equal antero-posterior centra lengths, and fusion of the sacral vertebrae) with MWC 5627 are neotheropods. We hesitate to diagnose this sacrum to the specific level, as specific autapomorphies for *Coelophysis* or other theropods are not present within the sacrum. Nevertheless, the characteristics described above show that MWC 5627 is a neotheropod sacrum that shows significant similarity in comparative dimensions and overall morphology to that of *Coelophysis,* and we diagnosis it as a neotheropod.

FOUR ACES MINE SPECIMENS

A study by Parrish (1999) found the presence of possible theropod and ornithischian dinosaurs based on the presence of several incomplete ungual phalanges (UCM 76197), several caudal vertebrae (UCM 76198), and a fragmentary right mandible (UCM 76501) from the Four Aces mine locality near the mouth of White Canyon (figure 1). The caudal vertebrae described by Parrish (1999) were diagnostic based on the subhexagonal cross section in the vertebrae, which Parrish (1999) claimed are diagnostic of *C. bauri* without supporting evidence. From examination of *C. bauri* specimens at

MNA, GRMP, and NMMNHS we do not agree that *C. bauri* can be diagnosed from a subhexagonal cross section of the caudal vertebrae (personal observation of Robert Gay) as the morphology exhibited in undisputed *C. bauri* specimens tends to be more box-like, a plesiomorphic condition within Archosauria. Based on this, we disagree that the vertebrae are truly diagnostic to Theropoda, or even of Archosauria. As for the phalanges (UCM 76197) and the mandible (UCM 76501), both are too incomplete to be diagnostic. Parrish (1999) indicates that most specimens are only possibly referable to Theropoda, and cannot be confidently placed within this clade. Considering the lack of synapomorphies present in the specimens described by Parrish (1999), we disagree with the placement of the published Four Aces mine specimens in Dinosauria. Instead, these specimens are best considered Archosauriformes *incertae sedis* until further work is conducted. In particular, UCM 76501 is of interest considering that since 1999, the ornithischian dinosaur record from the Triassic has been substantially revised (Irmis and others, 2007).

RESULTS

A critical review of the published literature on dinosaur remains from the State of Utah has revealed that all previously described dinosaurian body fossils cannot confidently be assigned to Dinosauria. The ichnofossil record of Dinosauria is likely better but because of substrate variation, convergence in the foot, and lack of precise discriminate methods to differentiate between theropods and non-dinosaurian archosaurs we urge caution in interpreting footprints as unambiguously dinosaurian. A sacrum from the Upper Triassic Chinle Formation near Moab possesses characters indicating a neotheropod origin and is referred to Neotheropoda based on structural similarities and the morphology of the sacral vertebrae. This specimen comprises the entirety of the body fossil record of dinosaurs from the Triassic Period in the State of Utah currently.

DISCUSSION

The Triassic Period, as preserved in the American West, has offered some of the most complete specimens of early dinosaurs ever found (Colbert, 1989). Despite this, dinosaur remains have proven to be rare outside of special preservational environments, like those found at Ghost Ranch, New Mexico. That so few specimens of confirmed dinosaurs have been reported from the extensive outcrops of Utah and Arizona is surprising, but given the diversity of large carnivorous and herbivorous non-dinosaurian archosaurs during the Late Triassic, it may be that dinosaurs were indeed rare in most Chinle environments. As Utah sits today (as it would have during Chinle depositional times) at a higher latitude than the extensive dinosaur-producing quarries of New Mexico, these specimens further support previous hypotheses that dinosaur radiation was limited by many factors including increasing paleolatitude (Irmis and others, 2011; Whiteside and others, 2015). Additional, more complete dinosaur specimens from Utah's Triassic will help further support or disprove this idea.

Our confirmation of Late Triassic dinosaurs in Utah is based on rather fragmentary material, compared with known specimens from New Mexico and Arizona. This may not be surprising, as few specimens of any identity are known from mudstone deposits in Utah. Only the Comb Ridge sites, Indian Creek, and some in the Red Canyon, that we are aware of, regularly produce vertebrate material from mudstone; very few identifiable archosaurian specimens from the Moab or Lisbon Valley areas come from mudstones, and most originate in conglomeratic beds, though this is likely due to a sampling issue. Thus, the sacrum described here from Moab and numerous phytosaur skulls found in Lisbon Valley occur as isolated elements in conglomerates. The fragmentary nature of the specimens from conglomerates at more northern sites probably relates to an overall sandier section comprising the Chinle in those areas; Comb Ridge is more similar to sites in Red Canyon and Arizona in having a higher percentage of mudstone (Petrified Forest Member). As demonstrated by MWC 5627, a sacrum found in an area otherwise known for only very fragmentary vertebrate remains in the Chinle, more complete material may eventually be found near Moab or in Lisbon Valley or many other areas in the state. It is hoped that additional fieldwork in these areas will add to our understanding of early dinosaur radiation into the American Southwest.

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REFERENCES

Bakker, R.T., 1986, The dinosaur heresies—new theories unlocking the mystery of the dinosaurs: New York, Citadel Press, 481 p.

Blakey, R.C., and Gubitosa, R., 1983, Late Triassic paleogeography and depositional history of the Chinle Formation, southern Utah and northern Arizona, *in* Reynolds, M.W., and Dolly, E.D., editors, Mesozoic paleogeography of west-central United States: Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, p. 57–76.

Blakey, R.C., and Gubitosa, R., 1984, Controls of sandstone body geometry and architecture in the Chinle Formation (Upper Triassic), Colorado Plateau: Sedimentary Geology, v. 38, p. 51–86.

Baron, M.G., Norman, D.B., and Barrett, P.M., 2017, A new hypothesis of dinosaur relationships and early dinosaur evolution: Nature, v. 543, p. 501–506, doi:10.1038/nature21700.

Britt, B.B., Chure, D.J., Engelmann, G.F., and Shumway, J.D., 2016, Rise of the erg—paleontology and paleoenvironments of the Triassic–Jurassic transition in northeastern Utah: Geology of the Intermountain West, v. 3, p. 1–32.

Britt, B.B., Chure, D.J., Engelmann, G., Dalla Vecchia, F., Scheetz, R.D., Meek, S., Thelin, C., and Chambers, M., 2015, A new, large non-pterodactyloid pterosaur from a Late Triassic interdunal environment within the eolian Nugget Sandstone of northeastern Utah, USA, indicates early pterosaurs were ecologically diverse and geographically widespread [abs.]: Journal of Vertebrate Paleontology Program and Abstracts, SVP 75th Annual Meeting p. 97.

Brusatte, S.L., Niedźwiedzki, G., and Butler, R.J., 2011, Footprints pull origin and diversification of dinosaur stem lineage deep into Early Triassic: Proceedings of the Royal Society of London B: Biological Sciences, v. 278, no. 1708, p. 1107–1113.

Bunker, C.M., 1957, Theropod saurischian footprint discovery in the Wingate (Triassic) Formation: Journal of Paleontology v. 31, p. 973.

Butler, R.J., Smith, R.M., and Norman, D.B., 2007, A primitive ornithischian dinosaur from the Late Triassic of South Africa, and the early evolution and diversification of Ornithischia: Proceedings of the Royal Society B: Biological Sciences, v. 274, p. 2041–2046.

Carpenter, K., 1997, A giant coelophysoid (Ceratosauria) theropod from the Upper Triassic of New Mexico: Neues Jahrbuch fur Geologie und Palaontologie-Abhandlungen, v. 205, p.189–208.

Chambers, M., Hales K., Britt, B.B., Chure, D.J., Engelmann, G., and Scheetz, R.D., 2011, Preliminary taphonomic analysis of a Coelophysoid theropod dinosaur bonebed in the Early Jurassic Nugget Sandstone of Utah [abs.]: Geological Society of America Abstracts with Programs, v. 42, no. 4, p. 16.

Colbert, E.H., 1989, The Triassic dinosaur Coelophysis: Museum of Northern Arizona Bulletin 57, 160 p.

Dzik, J., 2003, A beaked herbivorous archosaur with dinosaur affinities from the early Late Triassic of Poland: Journal of Vertebrate Paleontology, v. 23, p. 556–574.

Engelmann, G.F., Chure, D.J., Britt, B.B., and Andrus, A., 2012, The biostratigraphic and paleoecological significance of a new drepanosaur from the Triassic-? Jurassic Nugget Sandstone of northeastern Utah [abs.]: Geological Society of America Abstracts with Programs, v. 44, no. 7, p. 604.

Farlow, J.O., Schachner, E.R., Sarrazin, J.C., Klein, H., and Currie, P.J., 2014, Pedal proportions of *Poposaurus gracilis*—convergence and divergence in the feet of archosaurs: The Anatomical Record, v. 297, no. 6, p. 1022–1046.

Foster, J.R., Titus, A.L., Winterfeld, G.F., Hayden, M.C., and Hamblin, A.H., 2001, Paleontological survey of the Grand Staircase-Escalante National Monument, Garfield and Kane Counties, Utah: Utah Geological Survey Special Study 99, 98 p.

Gaston, R., Lockley, M., Lucas, S., and Hunt, A., 2003, Grallator-dominated fossil footprint assemblages and associated enigmatic footprints from the Chinle Group (Upper Triassic), Gateway area, Colorado: Ichnos, v. 10, no. 2–4, p. 153–163.

Gauthier, J.A., Nesbitt, S.J., Schachner, E.R., Bever, G.S., and Joyce, W.G., 2011, The bipedal stem crocodilian *Poposaurus gracilis*—inferring function in fossils and innovation in archosaur locomotion: Bulletin of the Peabody Museum of Natural History, v. 52, p. 107–126.

Griffin, C.T., Stefanic, C.M., Parker, W.G., Hungerbühler, A., and Stocker, M.R., 2017, Sacral anatomy of the phytosaur *Smilosuchus adamanensis*, with implications for pelvic girdle evolution among Archosauriformes: Journal of Anatomy, doi:10.1111/joa.12681.

Hamblin, A.H., and Foster, J.R., 2000, Ancient animal footprints and traces in the Grand Staircase-Escalante National Monument, south-central Utah, *in* Sprinkel, D.A., Chidsey, T.C., Jr., and Anderson, P.B., editors, Geology Utah's parks and monuments: Utah Geological Association Publication 28 (first edition), p. 569–578, available online, http://www.utahgeology.org/pub28_pdf_files/Hamblin.pdf.

Hendrickx, C., Hartman, S.A., and Mateus, O., 2015, An overview of non-avian theropod discoveries and classification: PalArch's Journal of Vertebrate Palaeontology, v. 12, no. 1, p 1–73.

Hunt, A.P., and Lucas, S.G., 2007, Late Triassic tetrapod tracks of western North America: New Mexico Museum of Natural History and Science Bulletin 40, p. 215–230.

Irmis, R.B., Chure, D.J., Engelmann, G.F., Wiersma, J.P., and Lindström, S., 2015, The alluvial to eolian transition of the Chinle and Nugget Formations in the southern Uinta Mountains, northeastern Utah, *in* Vanden Berg, M.D., Ressetar, R., and Birgenheier, L.P., editors, Geology of Utah's Uinta Basin and Uinta Mountains: Utah Geological Association Publication 44, p. 13–48.

Irmis, R.B., Nesbitt, S.J., Padian, K., Smith, N.D., Turner, A.H., Woody, D., and Downs, A., 2007, A Late Triassic dinosauromorph assemblage from New Mexico and the rise of dinosaurs: Science, v. 317, p. 358–361.

Irmis, R.B., Mundil, R., Martz, J.W., and Parker W.G., 2011, High-resolution U–Pb ages from the Upper Triassic Chinle Formation (New Mexico, USA) support a diachronous rise of dinosaurs: Earth Planet Science Letters, v. 309, p. 258–267.

Kent, D.V., Malnis, P.S., Colombi, C.E., Alcober, O.A., and Martínez, R.N., 2014, Age constraints on the dispersal of dinosaurs in the Late Triassic from magnetochronology of the Los Colorados Formation (Argentina): Proceedings of the National Academy of Sciences, v. 111, p. 7958–7963.

Lockley, M.G., and Hunt, A.P., 1995, Dinosaur tracks and other fossil footprints of the western United States: New York, Columbia University Press, 338 p.

Long, R.A., and Murry, P.A.,1995, Late Triassic (Carnian and Norian) tetrapods from the southwestern United States: New Mexico Museum of Natural History and Science Bulletin 4, 254 p.

Lucas, S.G., and Heckert, A.B., 2000, Dinosaurs of New Mexico: New Mexico Museum of Natural History and Science Bulletin 17, 230 p.

Marsicano, C.A., Domnanovich, N.S., and Mancuso, A.C., 2007, Dinosaur origins—evidence from the footprint record: Historical Biology, v. 19, p. 83–91.

Marsh, O.C., 1881, Principal characters of American Jurassic dinosaurs, Part V: The American Journal of Science and Arts, Series 3, v. 21, p. 417–423.

Martill, D.M., Vidovic, S.U., Howells, C., and Nudds, J.R., 2016, The oldest Jurassic dinosaur—a basal neotheropod from the Hettangian of Great Britain: PLoS ONE, v. 11, no. 1, p. 1–38.

Martinez, R.N., Sereno, P.C., Alcober, O.A., Colombi, C.E., Renne, P.R., Montanez, I.P., and Currie, B.S., 2011, A basal dinosaur from the dawn of the dinosaur era in southwestern Pangaea: Science, v. 331, p. 206–210.

Martz, J.W., Irmis, R.G., and Milner, A.R.C., 2014, Lithostratigraphy and biostratigraphy of the Chinle Formation (Upper Triassic) in southern Lisbon Valley, southeastern Utah, *in* MacLean, J.S., Biek, R.F., and Huntoon, J.E., editors, Geology of Utah's far south: Utah Geological Association Publication 43, p. 397–446.

Martz, J.W., Kirkland, J.I., Milner, A.R.C., Parker, J.W., and Santucci, V.L., 2017, Upper Triassic lithostratigraphy, depositional systems, and vertebrate paleontology across southern Utah: Geology of the Intermountain West, v. 4, p. 99–180.

Nesbitt, S.J., 2011, The early evolution of archosaurs—relationships and the origin of major clades: Bulletin of the American Museum of Natural History, v. 352, p. 1–292. doi:10.1206/352.1.

Nesbitt, S.J., Irmis, R.B., and Parker, W.G., 2007, A critical re-evaluation of the Late Triassic dinosaur taxa of North America: Journal of Palaeontology, v. 5, no. 2, p. 209–243.

Nesbitt, S.J., Smith, R.B., Irmis, R.B., Turner, A.D., and Norell, M.A., 2009, A complete skeleton of a Late Triassic saurischian and the early evolution of dinosaurs: Science, v. 326, p. 1530–1533.

Niedźwiedzki, G., Brusatte, S.L., and Butler, R.J., 2013, Prorotodactylus and Rotodactylus tracks—an ichnological record of dinosauromorphs from the Early–Middle Triassic of Poland, *in* Nesbitt, S.J., Desojo, J.B., and Irmis, R.B., editors, Anatomy, phylogeny, and paleobiology of early archosaurs and their kin: London, Geological Society Special Publications 379, p. 319–351.

Olsen, P., Smith, J.B., and McDonald, N.G., 1998, Type material of the type species of the classic theropod footprint genera *Eubrontes*, *Anchisauripus*, and *Grallator* (Early Jurassic, Hartford and Deerfield Basins, Connecticut and Massachusetts, USA):

Journal of Vertebrate Paleontology, v. 18, p. 586–601.

Padian, K., 1986, On the type material of *Coelophysis* (Saurischia: Theropoda) and a new specimen from the Petrified Forest of Arizona (Late Triassic: Chinle Formation), *in* Padian, K., editor, The beginning of the age of dinosaurs—faunal change across the Triassic-Jurassic boundary: Cambridge, UK, Cambridge University Press, p. 45–60.

Padian, K., Hutchinson, J.R., and Holtz, T.R., 1999, Phylogenetic definitions and nomenclature of the major taxonomic categories of the carnivorous dinosauria (Theropoda): Journal of Vertebrate Paleontology, v. 19, p. 69–80.

Parrish, J.M., 1999, Small fossil vertebrates from the Chinle Formation (Upper Triassic) of southern Utah: Utah Geological Survey Miscellaneous Publication 99-1, p. 45–50.

Parrish, J.M., and Lockley, M.G., 1984, Dinosaur trackways from the Triassic of western Colorado [abs.]: Geological Society of America Abstracts with Programs, v. 16, no. 4, p. 250.

Parker, W.G., and Martz, J.W., 2011, The Late Triassic (Norian) Adamanian–Revueltian tetrapod faunal transition in the Chinle Formation of Petrified Forest National Park, Arizona: Earth and Environmental Science Transactions of the Royal Society of Edinburgh, v. 101, no. 3–4, p. 231–260.

Ramezani, J., Hoke, G.D., Fastovsky, D.E., Bowring, S.A., Therrien, F., Dworkin, S.I., Atchley, S.C., and Nordt, L.C., 2011, High-precision U-Pb zircon geochronology of the Late Triassic Chinle Formation, Petrified Forest National Park (Arizona, USA)—temporal constraints on the early evolution of dinosaurs: Geological Society of America Bulletin, v. 123, no. 11–12, p. 2142–2159.

Rauhut, O.W., and Hungerbühler, A., 2000, A review of European Triassic theropods: Gaia, v. 15, p. 75–88.

Riggs, E.S., 1904, Dinosaur footprints from Arizona: The American Journal of Science, Series 4, v. 17, no. 102, p. 432–424.

Rinehart, L.F., Lucas, S.G., Heckert, A.B., Spielmann, J.A., and Celeskey, M.D., 2009, The paleobiology of *Coelophysis bauri* (Cope) from the Upper Triassic (Apachean) Whitaker quarry, New Mexico, with detailed analysis of a single quarry block: New Mexico Museum of Natural History and Science Bulletin 45, 260 p.

Santucci, V.L., Hunt, A.P., Nyborg, T., and Kenworthy, J.P., 2006, Additional fossil vertebrate tracks in National Park Service areas, *in* Lucas, S.G., Spielmann, J.A., Hester, P.M., Kenworthy, J.P., and Santucci, V.L., editors, America's antiquities—100 years of managing fossils on federal lands: New Mexico Museum of Natural History and Science Bulletin 34, p. 152–158.

Schwartz, H.L., and Gillette, D.D., 1994, Geology and taphonomy of the *Coelophysis* quarry, Upper Triassic Chinle Formation, Ghost Ranch, New Mexico: Journal of Paleontology, v. 68, no. 5, p. 1118–1130.

Sereno, P.C., 1999a, A rationale for dinosaurian taxonomy: Journal of Vertebrate Paleontology, v. 19, p. 788–790.

Sereno, P.C., 1999b, The evolution of dinosaurs: Science, v. 284, p. 2137–2147.

Sereno, P.C., 2012, Taxonomy, morphology, masticatory function and phylogeny of heterodontosaurid dinosaurs: ZooKeys, v. 226, p. 1–225.

Shumway, J.B., Britt, B.B., Chure, D.J., Engelmann, G.F., Scheetz, R.D, Hood, S., and Chambers, M., 2016, Facies analysis and depositional environments of the Saints and Sinners quarry (SSQ) in the Lower Nugget Sandstone (Late Triassic) of northeastern Utah show that the diverse vertebrate assemblage was preserved in a lacustrine interdunal environment [abs.]: Journal of Vertebrate Paleontology Program and Abstracts, p. 224.

Sprinkel, D.A., Kowallis, B.J., and Jensen, P.H., 2011, Correlation and age of the Nugget Sandstone and Glen Canyon Group, Utah, *in* Sprinkel, D.A., Yonkee, W.A., and Chidsey, T.C., Jr., editors, Sevier thrust belt—northern and central Utah and adjacent areas: Utah Geological Association Publication 40, p. 131–149.

Stewart, J.H., Poole, F.G., Wilson, R.F., Cadigan, R.A., Thordarson, W., and Albee, H.F., 1972, Stratigraphy and origin of the Chinle Formation and related Upper Triassic strata in the Colorado Plateau region: U.S. Geological Survey Professional Paper 690, p. 336, 5 plates, scale 1:2,500,000.

Sues, H.D., Nesbitt, S.J., Berman, D.S., and Henrici, A.C., 2011, A late-surviving basal theropod dinosaur from the latest Triassic of North America: Proceedings of the Royal Society of London B: Biological Sciences, p.rspb20110410.

Weinbaum, J.C., and Hungerbuhler, A., 2007, A revision of *Poposaurus gracilis* (Archosauria: Suchia) based on two new specimens from the Late Triassic of the southwestern USA: Paläontologische Zeitschrift, v. 81, no. 2, p. 131–145.

Whiteside, J.H., Lindström, S., Irmis, R.B., Glasspool, I.J., Schaller, M.F., Dunlavey, M., and Turner, A.H., 2015, Extreme ecosystem instability suppressed tropical dinosaur dominance for 30 million years: Proceedings of the National Academy of Science, v. 112, p. 7909–7913, doi:10.1073/pnas.1505252112.