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TRACE FOSSILS FROM THE LOWER PERMIAN YESO GROUP, OTERO MESA, OTERO COUNTY, NEW MEXICO

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ABSTRACT—At Otero Mesa in Otero County, southern New Mexico, the Otero Mesa Formation of the Lower Permian Yeso Group is ~ 52 m of red-bed siliciclastic mudstone and ripple-laminated sandstone. Fossils from the Otero Mesa Formation documented here are walchian conifers, invertebrate ichnofossils (*Augerinoichnus helicoidalis*, *Dendroidichnites irregulare*, *Scoyenia gracilis*) and tetrapod footprints (*Batrachichnus salamandroides*, *Dromopus lacertoides*, *Dimetropus* ichnosp.). The ichnoassemblage of the Otero Mesa Formation closely resembles those of the Abo and Robledo Mountains Formations to the west, and well represents the *Dimetropus* ichnocoenosis of the *Batrachichnus* ichnofacies. It supports correlation of the Otero Mesa Formation to the lithologically similar Lee Ranch Member of the Abo Formation; both units yield ichnoassemblages of the *Dromopus* biochron. This correlation identifies a diachronous base of the Yeso Group in the Sacramento Mountains-Otero Mesa area. Correlation of the Lee Ranch Tongue of the Abo Formation and Otero Mesa Formation to the Deer Mountain Red Shale Member of the Alacran Mountain Formation in the Hueco Mountains of West Texas identifies a single, red-bed interval during the late Wolfcampian and thus is the most parsimonious event stratigraphic correlation.

INTRODUCTION

New Mexico has a world famous record of Early Permian fossil footprints. Most of these footprints and other associated trace fossils are from the Abo Formation and homotaxial red beds of the Robledo Mountains Formation that crop out in the mountain ranges that border the Rio Grande Valley (e.g., Lucas and Heckert, 1995; Lucas et al., 2011b, 2013b; Minter and Braddy, 2009; Voigt et al., 2013). However, other footprint assemblages are known from the Sangre de Cristo Formation near Las Vegas in northern New Mexico, and from Yeso Group strata, especially east of Socorro (e. g., Hunt et al., 1990; Lucas et al., 2013a). Here, I add to this record trace fossils from the lower part of the Yeso Group (Otero Mesa Member of Yeso Formation of Bachman and Hayes, 1958) at Otero Mesa in Otero County, southern New Mexico (Fig. 1). These trace fossils help to resolve a problem of Abo-Yeso-Hueco correlation between the southern Sacramento Mountains, Otero Mesa and the Hueco Mountains of West Texas.

STRATIGRAPHIC CONTEXT

The Lower Permian Yeso Group (Formation) is one of the most extensively exposed stratigraphic units of Permian age in New Mexico. From northern New Mexico (Sandoval County), through the uplifts that adjoin the Rio Grande Valley, southward to Las Cruces, and across the mountain ranges of southeastern New Mexico, Yeso strata are as much as 350 m thick and are primarily recognized by their gypsum beds (e. g., Needham and Bates, 1943; Kottlowski et al., 1956; Pray, 1961; Dinterman, 2001; Mack and Dinterman, 2002; Kues and Giles, 2004; Lucas et al., 2005, 2013a; Lucas and Krainer, 2012). Yeso Group deposition took place along the vast northwestern shelf of the Permian basin during part of Early Permian (Leonardian) time. To the northwest, the De Chelly erg, which covered much of the Four Corners and southern Colorado Plateau, represents the northwestern limit of the Yeso lithosome. To the southeast, in the Permian basin, Yeso strata grade into/interfinger with marine strata of the Bone Spring Formation. The extensive area in between these extremes was of low relief and variably covered by coastal dunes and sandflats, wadis, sabkhas and shallow marine shelves. Because of the nature of many Yeso facies—eolian, sabkha, evaporitic—Yeso strata have long been seen as relatively unfossiliferous. However, recent work has revealed a greater abundance of Yeso fossils than previously known, especially of terrestrial trace fossils and marine microfossils (Lucas et al., 2013a; Vachard et al., 2013).

The Yeso Formation of traditional usage consists of various members, some of which are relatively thick (up to 250 m) and lithologically distinctive units that have been routinely mapped by various workers at reasonable scales (including 1:24,000). Because of this, Lucas et al. (2005) concluded that the Yeso members merit formation rank, so they raised the Yeso to group rank (also see Lucas et al., 2013a, and see Cather et al., 2013 for a different view of Yeso stratigraphic nomenclature). The thickness, lithologic distinctiveness and great areal extent of the Yeso subdivisions (traditional members), and the fact that some of them

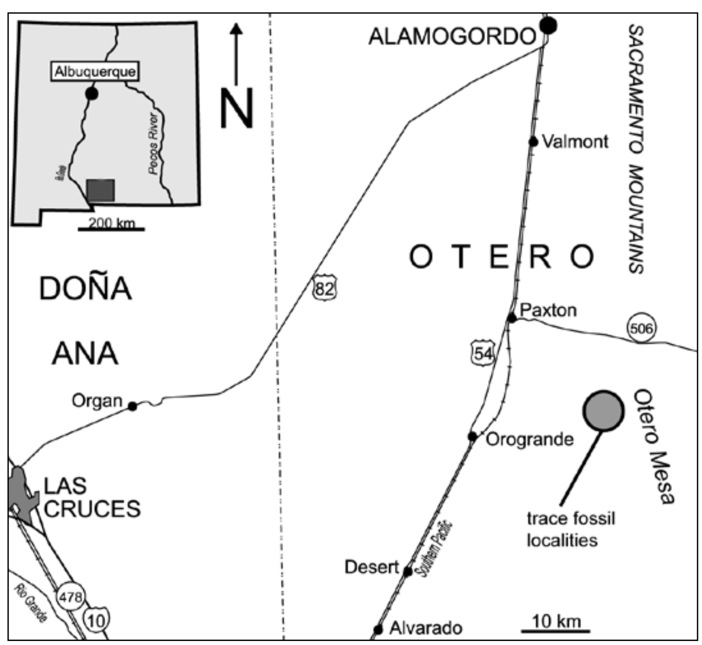

FIGURE 1. Location map showing area studied along western flank of Otero Mesa.

can be further subdivided, warranted raising Yeso to group rank. Broadly correlative or homotaxial units of similar thickness and extent are also group-rank units, such as the Clear Fork Group of Texas, the Supai Group of Arizona and the Cutler Group of the Four Corners.

In central New Mexico, the Yeso Group consists of a basal, clastic-dominated interval (DeChelly and Arroyo de Alamillo formations) overlain by a complex succession of gypsum, siltstone, dolomite and sandstone, the Los Vallos Formation. In collaboration with Karl Krainer, I have been studying Yeso stratigraphy in the Sacramento Mountains and Otero Mesa region of Otero County since 2012. Here, the Yeso lithofacies differ from those exposed towards the northwest and west (Bachman and Hayes, 1958; Pray, 1961; Black, 1973, 1975; Broadhead, 2002), and will merit some new lithostratigraphic nomenclature.

Pending completion of our studies, I use a mostly informal lithostratigraphic nomenclature to describe the Yeso Group section (~266 m thick) at Otero Mesa (Fig. 2).

Thus, I divide Yeso strata there into four lithostratigraphic units:

1) Unit A is the lowermost interval of the Yeso Group, ~51 m thick, and consists of interbedded gypsum, siltstone and dolostone. The base of this unit is a 4 m thick bed of reddish gypsiferous siltstone that rests on limestone (wackestone) of the Cerro Alto Formation of the Hueco Group.
2) Unit B is the Otero Mesa Member of the Yeso Formation of Bachman and Hayes (1958), here raised to formation rank. The Otero Mesa Formation is 52 m thick and is composed of mostly reddish to brownish mudstone, siltstone and fine-grained sandstone (Fig. 2). Mudstone to siltstone is commonly laminated and in places poorly exposed. Siltstone to fine-grained sandstone beds are 0.1–1.2 m thick, mostly reddish to brownish, and rarely greenish. Sedimentary structures are horizontal lamination, ripple lamination, rare climbing ripples, and massive sandstone. Rarely, mudcracks are observed. Distinctive beds contain abundant burrows (*Scoyenia*, *Skolithos*), walchian conifer impressions and vertebrate footprints, documented here (Fig. 2). One thin (0.1 m), laminated dolomite bed and one muddy nodular red calcrete bed (0.2 m) are also present.
3) Unit C is ~53 m thick and consists of gypsum (up to 4.5 m thick), gypsiferous siltstone (up to 5 m thick), red siltstone (up to 7.2 m thick), greenish shale and siltstone (partly laminated and up to 1 m thick) and two horizons of bedded dolomite in the upper part.
4) Unit D is at least 119 m thick (its top is not exposed in the section we studied) and is mostly bedded dolomite, which occurs as: (1) thin-bedded dolomite; (2) thin-bedded and laminated dolomite (1–2 cm); (3) thick-bedded to massive dolomite; (4) intraformational breccia horizons, 1.8–6.4 m thick, composed of dm-size, angular dolomite clasts; and (5) rare, intercalated pale green shale (2.6 m thick).

In 2012, a field crew from the New Mexico Museum of Natural History in Albuquerque, New Mexico (NMMNH) collected trace fossils in the Otero Mesa Formation at 17 localities along the

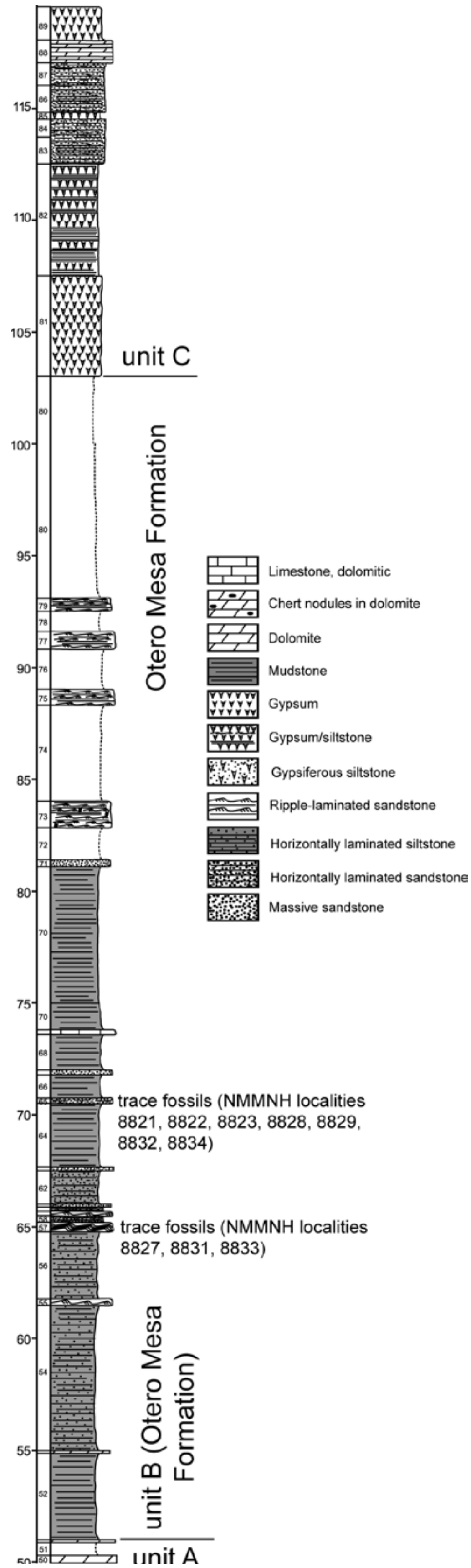

FIGURE 2. Section of Otero Mesa Formation at Otero Mesa showing stratigraphic position of trace fossil sites.

western flank of Otero Mesa in sections 2, 11 and 14, T22S, R10E. These trace fossils occur primarily at two stratigraphic levels in the lower part of the Otero Mesa Formation. The lowest fossiliferous bed is ripple-laminated sandstone ~14 m above the base of the formation; the most fossiliferous bed is a similar sandstone ~6 m higher (Fig. 2). The trace fossils occur in very fine grained sandstone or siltstone beds that have abundant ripple laminations (usually climbing ripples).

PALEONTOLOGY

Fossil Plants

Most of the trace fossil localities at Otero Mesa also yield impressions of fossil plants. These are of stems and foliage of walchian conifers; an example is NMMNH P-67750 from locality 8827. Such a low diversity, conifer-dominated assemblage is characteristic of siliciclastic red-bed floras of the Abo Formation and Robledo Mountains Formation at outcrops along the Rio Grande Valley (e.g., DiMichele et al., 2007; Lucas et al., 2013b).

Invertebrate Ichnofossils

Invertebrate ichnofossils from Otero Mesa are much less common than vertebrate footprints and represent three ichnotaxa.

Augerinoichnus helicoidalis **(Minter et al., 2008)**

Augerinoichnus is a hyporelief trace that can best be described as a linear succession of imbricated, horseshoe-shaped structures (Minter et al., 2008; Minter and Braddy, 2009). Three specimens readily assigned to *A. helicoidalis* were collected at Otero Mesa: NMMNH P-67768 from locality 8823, the largest specimen with a width of ~15 mm (Fig. 3B); P-67762 from locality 8830; and P-67745 from locality 8823. Minter et al. (2008) interpreted this trace as a bedding-plane section through the lower part of the coils of a horizontal, helical-shaped burrow made by a worm-like animal.

Dendroidichnites irregulare **(Holub and Kozur, 1981)**

One specimen from Otero Mesa, NMMNH P-67749 from locality 8823 (Fig. 3A), is a trail in concave epirelief readily assigned to *Dendroidichnites irregulare*. Thus, it consists of two parallel track rows of elongate tracks oriented obliquely to the trackway midline, not in series, and separated medially (cf. Minter and Braddy, 2009). External width of this trackway is 3–4 mm, and its total course is about 90 mm long. *Dendroidichnites* is interpreted as the trackway of a multi-limbed arthropod such as a myriapod walking on a soft substrate so that its body dragged along the trackway midline.

Scoyenia gracilis **(White, 1929)**

The most common invertebrate ichnofossil at Otero Mesa is *Scoyenia gracilis*, found at many localities. Some specimens are superbly preserved and show the horizontal to nearly horizontal backfilled burrows characteristic of the ichnospecies (for example, NMMNH P-67760 from locality 8823). Others, like the specimen illustrated here (Fig. 3C), are preserved in convex hyporelief with a characteristic wall ornamentation of small, convex, longitudinal scratch marks. These burrows range in diameter from 4 to 7 mm.

Scoyenia gracilis is a very common nonmarine ichnofossil typically associated with moist/wet substrates that were periodically inundated and has been regarded as a feeding and a

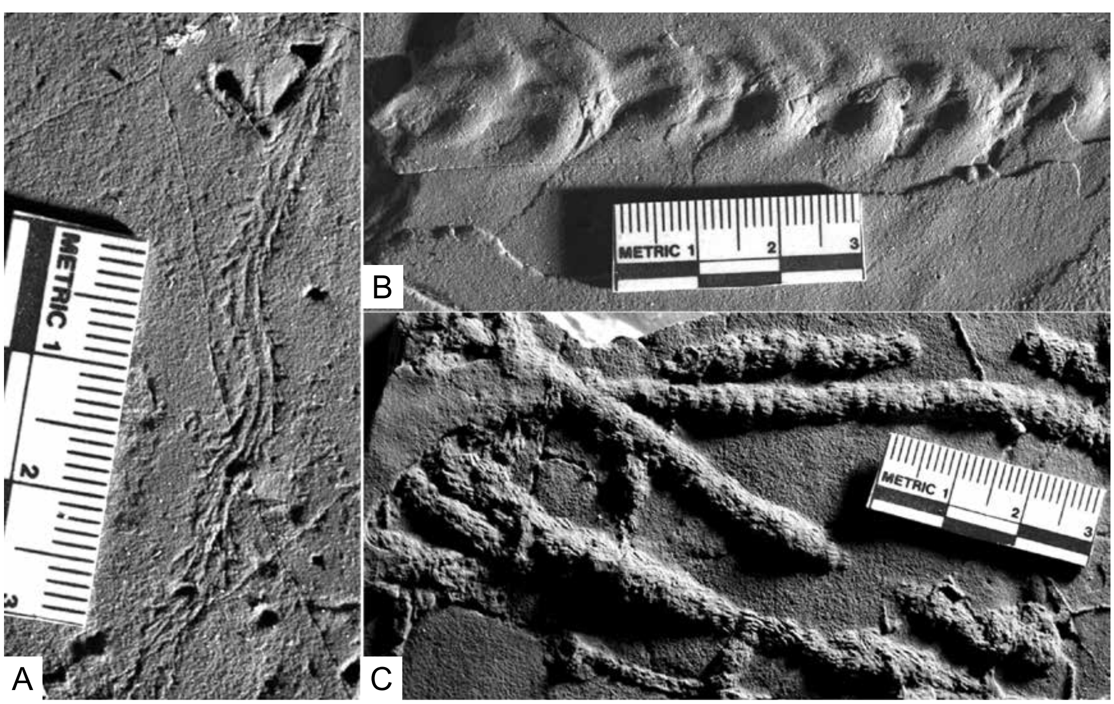

FIGURE 3. Selected invertebrate ichnofossils from the Otero Mesa Formation at Otero Mesa. A. *Dendroidichnites irregulare*, NMMNH P-67749 from locality 8823. B. *Augerinoichnus helicoidalis*, NMMNH P67768 from locality 8823. C. *Scoyenia gracilis*, NMMNH P-67733 from locality 8834.

locomotion trace (Frey et al., 1984). Proposed trace makers include insects, decapods and polychaetes (Metz, 1996).

Tetrapod Footprints

Tetrapod footprints are the most common fossils in the Otero Mesa Formation at Otero Mesa. The ichnoassemblage is dominated by *Batrachichnus* and *Dromopus*.

***Batrachichnus salamandroides* (Geinitz, 1861)**

By far the most abundant trace fossils at Otero Mesa are small (<20 mm long) footprints readily assigned to *Batrachichnus salamandroides*. Specimens in the NMMNH collection come from almost all of the sites collected, and are especially abundant at locality 8823. They range from isolated footprints to trackways (Fig. 4). *Batrachichnus* is the track of a very small to small quadruped in which pes length is usually less than 20 mm, and the pentadactyl pes is plantigrade to semiplantigrade (e.g., Haubold et al., 1995; Voigt, 2005). Pes digits I-III are closely grouped and serially increase in length; digit IV is the longest. Digit V is set somewhat posterior and lateral to the other digits. The manus is tetradactyl, semiplantigrade and a little smaller than the pes. On the manus, digit length increases from I to III, and digit IV, which is about as long as II, diverges outward. A body or tail drag may be seen in some trackways with deep imprints.

A wide range of extramorphological variation is present in the Otero Mesa *Batrachichnus* sample, as is characteristic of large samples of *Batrachichnus* (e.g., Haubold et al., 1995; Melchor and Sarjeant, 2004; Voigt, 2005; Minter and Braddy, 2009; Lucas et al., 2011c). Thus, tridactyl manus and pes underprints are present, as are tetradactyl pes impressions. Digits are normally short, straight and blunt tipped, but slightly curved digits and pointed digit tips are present as well. Elongate, scratch-like digits can be seen on some specimens. *Batrachichnus* is widely regarded as the footprint of a small temnospondyl amphibian, and is very common in many Early Permian red-bed ichnoassemblages (Haubold, 1971, 1996, 2000; Gand and Durand, 2006; Lucas, 2007; Voigt et al., 2011).

***Dromopus lacertoides* (Geinitz, 1861)**

Tracks of *Dromopus* are lacertoid and show a strong increase in digit length from digits I to IV, which are slightly incurved distally (Fig. 5A-C). The Otero Mesa specimens are mostly tridactyl underprints of digits II to IV or III to V on trampled surfaces (for example, at locality 8829; Fig. 5A-B). Pes length does not exceed 35 mm, and most of the specimens from Otero Mesa are much smaller, less than 10 mm long. Size and morphology correspond well to *Dromopus lacertoides* (e.g., Haubold et al., 1995; Voigt, 2005; Lucas et al., 2011c). *Dromopus* is a very common kind of late Paleozoic tetrapod footprint known from almost all significant ichnofaunas of Early Permian age (e.g., Haubold, 1971, 1996, 2000; Lucas and Heckert, 1995; Voigt, 2005; Gand and Durand, 2006; Lucas, 2007; Voigt et al., 2011). Potential trackmakers are small to medium-sized diapsid reptiles, including araeoscelids.

***Dimetropus* isp.**

One large footprint from Otero Mesa preserved in convex hyporelief, NMMNH P-67752 from locality 8834 (Fig. 5D), is about 60 mm long and 45 mm wide. It is pentadactyl with long, thin digits with pointed tips. Digits I and V are relatively short, and digit V is everted. Digits II, III and IV are much longer than I and V, and digit IV is longest. There appears to have been a relatively large “sole” impression. These features are diagnostic of the pelycosaur footprint ichnogenus *Dimetropus*, to which it is assigned, but because of poor preservation and its isolated occurrence, no ichnospecies assignment is attempted (cf. Haubold, 1971; Voigt, 2005).

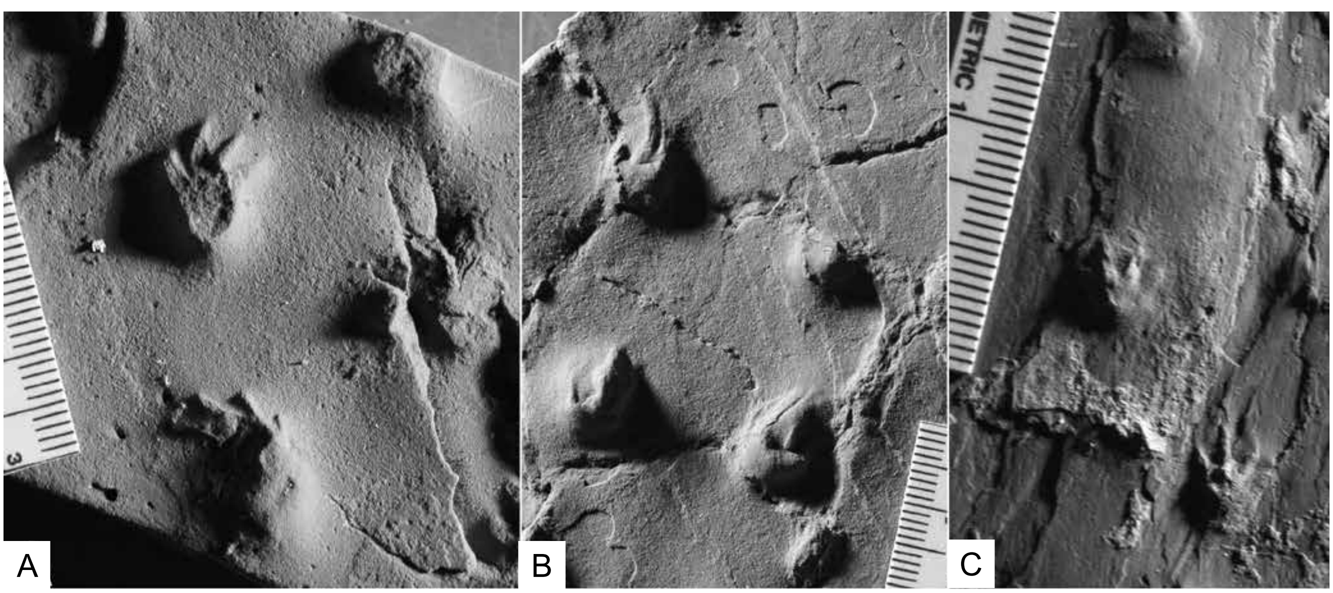

FIGURE 4. *Batrachichnus salamandroides* from the Otero Mesa Formation at Otero Mesa. A. NMMNH P-67741 from locality 8823. B. NMMNH P-67732 from locality 8830. C. NMMNH P-67758 from locality 8956.

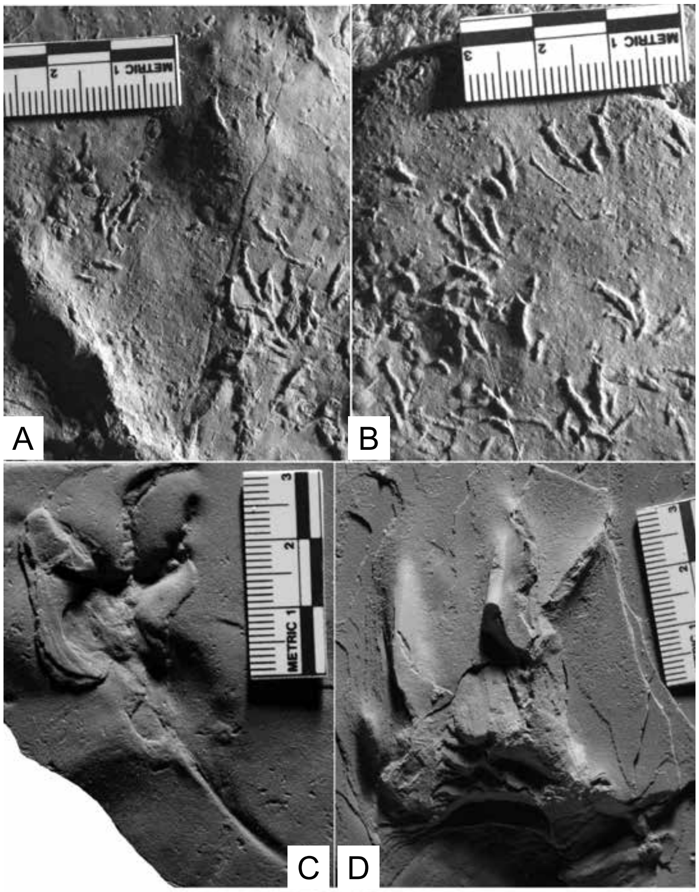

FIGURE 5. *Dromopus lacertoides* (A-C) and *Dimetropus* ichnosp., with (D) from the Otero Mesa Formation at Otero Mesa. A-B. NMMNH P-67731 from locality 8829. C. NMMNH P-67763 from locality 8830. D. NMMNH P-67752 from locality 8834.

Ichnofacies

The Otero Mesa ichnofossil assemblage includes arthropod burrows, arthropod locomotion traces and tetrapod locomotion traces, so it corresponds well to the *Scoyenia* ichnofacies as used by Buatois and Mángano (2007). It indicates a terrestrial invertebrate fauna that consists of a mobile epifauna as well as a shallow, burrowing infauna and a tetrapod fauna of quadrupedal predators. In terms of the tetrapod footprint ichnofacies introduced by Hunt and Lucas (2007), the Otero Mesa tetrapod footprints clearly pertain to the *Batrachichnus* ichnofacies.

In the New Mexico Wolfcampian footprint record, Hunt and Lucas (2006, 2007) divided the *Batrachichnus* ichnofacies into three ichnocoenoses based on the presence of *Dimetropus* (coastal/tidal flats), *Amphisauropus* (alluvial plain) and *Ichniotherium* (inland—distal alluvial fan) (also see Minter and Braddy, 2009). The Otero Mesa tracksite has *Dimetropus* in association with abundant *Batrachichnus* and less common *Dromopus*, so it is readily recognized as representing the *Dimetropus* ichnocoenosis. Indeed, the stratigraphic relationships of the Otero Mesa Formation—between shallow marine/sabkha strata and pinching out into them not far south of Otero Mesa—indicate it was deposited near the coastline of the Hueco seaway.

DISCUSSION—CORRELATION OF THE OTERO MESA FORMATION

The footprint assemblage and the lithofacies of the Otero Mesa Formation are remarkably similar to those of the Abo Formation to the north, in the Sacramento Mountains, and in the Abo Formation and Robledo Mountains Formation outcrops of the Rio Grande Valley region. Thus, ichnoassemblages dominated by *Batrachichnus* and *Dromopus* with some *Dimetropus* are common in the Abo and Robledo Mountains formations (e. g., Lucas and Heckert, 1995; Lucas et al., 2011b; Minter and Braddy, 2009; Voigt and Lucas, 2013). *Augerinoichnus* also is known only from the Abo and Robledo Mountains formations. In contrast, ichnoassemblages of the lower part of the Yeso Group (Arroyo de Alamillo Formation) in central New Mexico are dominated by captorhinomorph tracks (especially of *Varanopus*), have only rare *Batrachichnus* and *Dromopus* and lack *Augerinoichnus* (Lucas et al., 2013a). The change in ichnoassemblages is the boundary between the *Dromopus* (older) and *Erpetopus* (younger) biochrons (Lucas, 2007; Voigt and Lucas, 2013). Based on its trace fossils, the Otero Mesa Formation thus can be correlated to the *Dromopus* biochron, not to the *Erpetopus* biochron, which is well characterized by trace fossils of the lower part of the Yeso Group in central New Mexico.

Bachman and Hayes (1958; also see Pray, 1961) did an excellent job of documenting the interfingering of Abo and Hueco lithofacies in the southern Sacramento Mountains. Thus, they identified two tongues of the Abo Formation separated by a tongue of the marine Hueco Group in the Sand Canyon-Culp Canyon area, ~12–15 km north-northeast of Otero Mesa. Bachman and Hayes (1958) referred to the lower Abo tongue as the Danley Ranch Tongue, and the upper tongue as the Lee Ranch Tongue, and Pray (1961) named the Hueco strata in between the Pendejo Tongue of the Hueco. At Culp Canyon, gypsum is at the base of the Yeso Group section above the Lee Ranch Tongue of the Abo Formation.

Farther south, near the northern end of Otero Mesa (at and around UTM zone 13, 420441E, 3593442N, NAD 83), Bachman and Hayes (1958) described part of the Yeso Group section (Fig. 6). Here, they identified a lower Yeso interval of interbedded gypsum and dolomite that rests on Hueco Group strata, overlain by the siliciclastic red beds they termed the Otero Mesa Member. This is overlain by more gypsiferous strata and capped by the dolomite-dominated upper part of the Yeso Group. I have examined Bachman and Hayes (1958) type section of the Otero Mesa Member, and the Hueco-Yeso section is essentially identical to the section exposed ~10 km farther south, on the western flank of Otero Mesa, from which the trace fossils documented here were collected.

The questions are how to correlate the Abo-Hueco-Abo-Yeso sections at Culp and Sand Canyons to the Hueco-Yeso section at Otero Mesa, and how to correlate it southward to the Hueco Group type section in the Hueco Mountains of West Texas? Bachman and Hayes (1958) correlated the Lee Ranch Tongue to a horizon in the upper part of the Hueco Group (these are strata of the Cerro Alto Formation) at Otero Mesa, and they equated

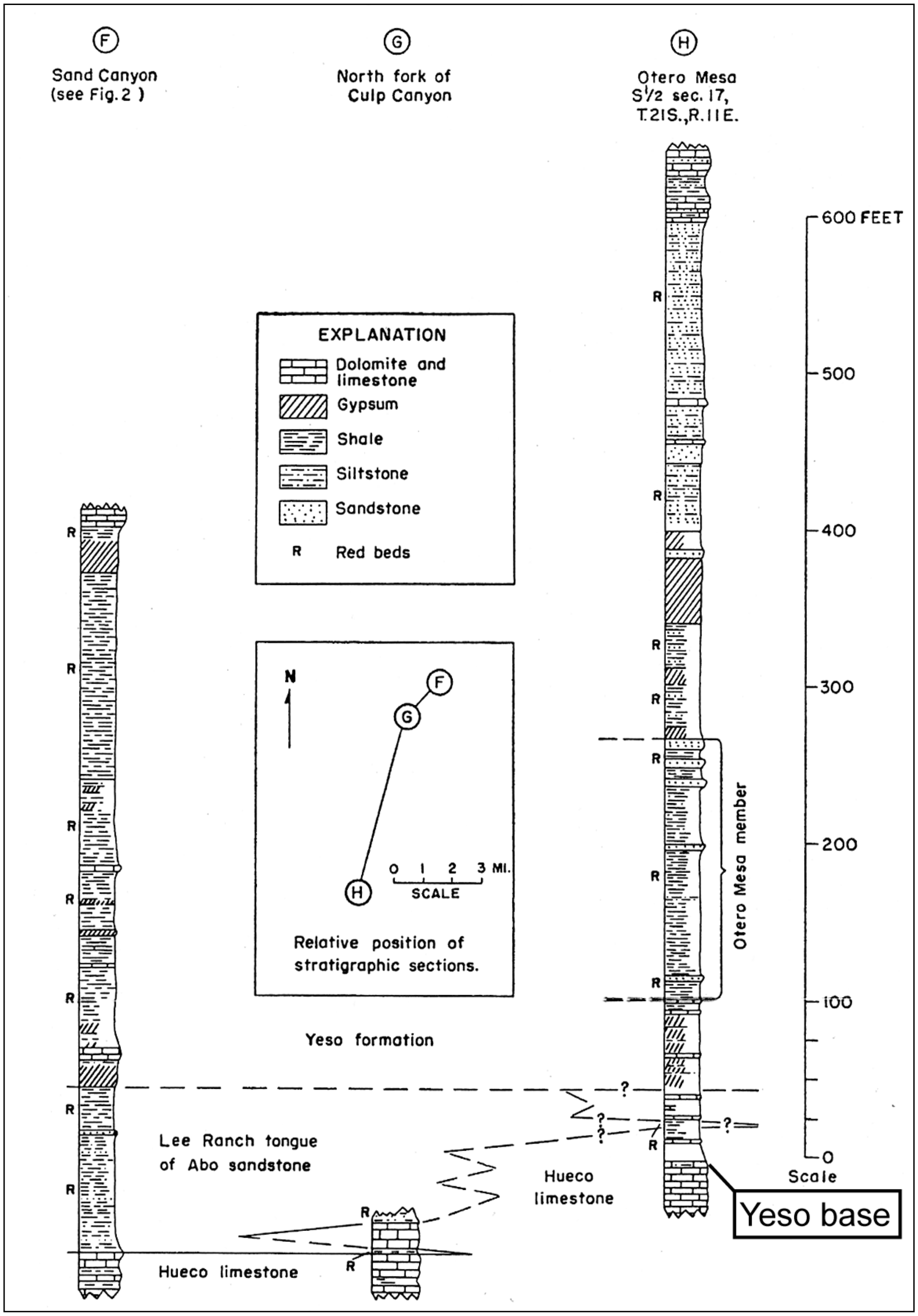

FIGURE 6. Correlation of Lee Ranch Tongue of Abo Formation to Yeso Group section at Otero Mesa (modified from Bachman and Hayes, 1958, fig. 4) with Yeso base advocated here indicated in lower right.

the lowest gypsum beds in both sections as the base of the Yeso Group. However, the red beds of the upper Hueco Group in their Otero Mesa section that they show as the southward pinchout of the Lee Ranch Tongue are very thin, red, gypsiferous siltstone interbedded with gypsum beds, so these are beds in the Yeso Formation by their definition. In other words, I judge their Yeso base to be almost at the base of their section at Otero Mesa, just at the contact of their basal limestone bed with overlying strata (Fig. 6).

Furthermore, I propose a different correlation than that advocated by Bachman and Hayes (1958), one that equates the Lee Ranch Tongue of the Abo with the Otero Mesa Formation of the Yeso Group (Fig. 7). This correlation is supported by the very similar lithology and thickness of the Lee Ranch and Otero Mesa units and their similar ichnofossil assemblages. Thus, note that in the Culp Canyon-Sand Canyon area, the Lee Ranch Tongue is 34–43 m thick and consists of siliciclastic red-bedded mudstone and ripple-laminated sandstone and thus is remarkably similar to the Otero Mesa Formation.

Particularly important to this correlation is the change in ichnofossil assemblages that occurs essentially at the Abo-Yeso contact in central New Mexico, discussed above. Thus, at this change, a large number of captorhinomorph tracks appear (particularly *Varanopus*), the dominance of footprint assemblages by *Batrachichnus* and *Dromopus* (characteristic of most of the Abo and of the Robledo Mountains formations' ichnoassemblages) stops and the shallow compaction burrow *Sphaerapus* appears (Lucas et al., 2013a, c). The trace fossil assemblage of the Otero Mesa Formation differs little from that of the Lee Ranch Tongue (under study by S. Voigt and myself) and is remarkably like that of the Abo and Robledo Mountains formations. In terms of the footprint biochronology proposed by Voigt and Lucas (2013), the Lee Ranch, Otero Mesa, Abo and Robledo Mountains ichnoassemblages can be assigned to the *Dromopus* biochron, whereas younger Yeso footprint assemblages from central New Mexico belong to the younger, *Erpetopus* biochron. This provides biostratigraphic support for a Lee Ranch-Otero Mesa correlation (Fig. 7).

It is important, nevertheless, to distinguish lithostratigraphic boundaries from biostratigraphic/chronostratigraphic boundaries. Thus, even though I advocate the correlation of the Lee Ranch Tongue (of the Abo Formation) with the Otero Mesa Formation (of

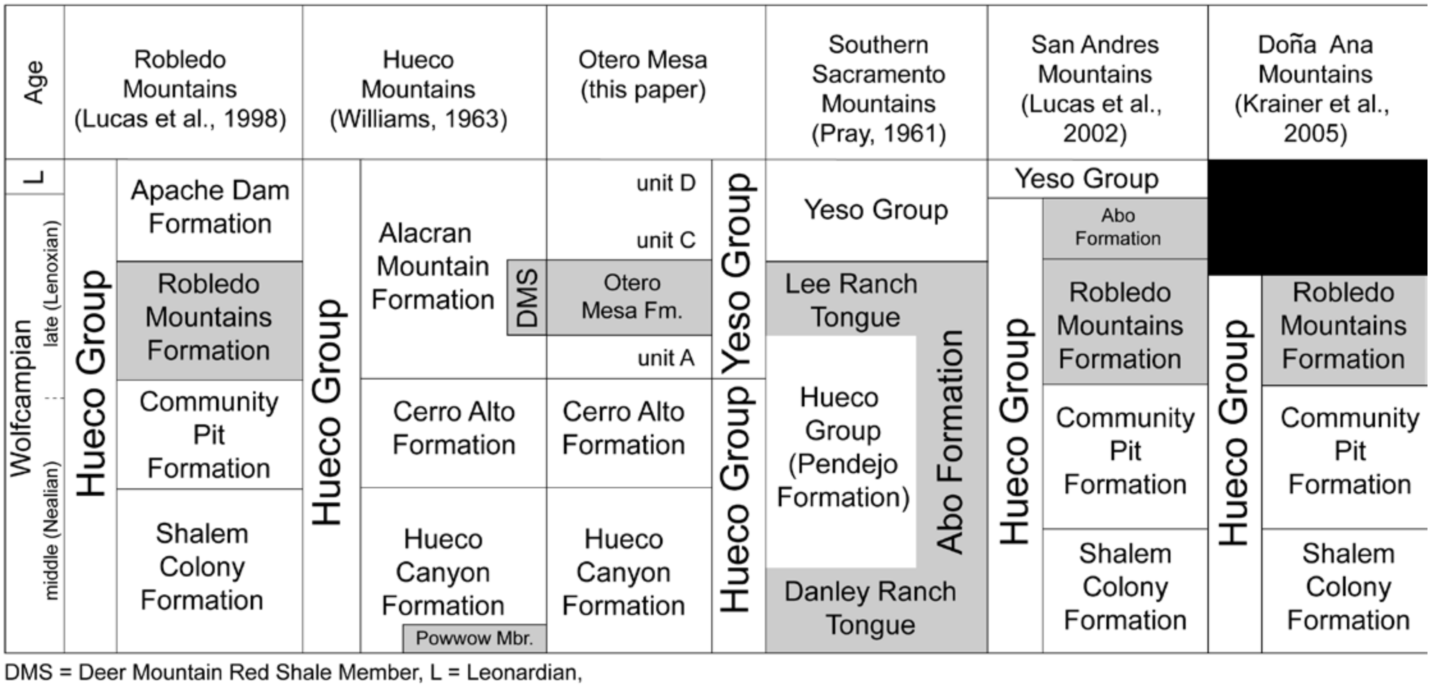

FIGURE 7. Regional correlation of the Abo Formation and Hueco Group.

the Yeso Group), I would retain the lithostratigraphic base of the Yeso Group of Bachman and Hayes (1958). Thus, the Yeso base is the first gypsum bed above the Abo Formation (Lee Ranch Tongue) at Culp Canyon, and it is the first gypsum bed above the Cerro Alto Formation of the Hueco Group (and thus well below the Otero Mesa Formation) at Otero Mesa (Fig. 6). This identifies a diachronous base of the Yeso Group between the Sacramento Mountains and Otero Mesa, but lithostratigraphic boundaries, which are lithofacies boundaries, need not be time lines.

So, the second part of the question is how to correlate the Otero Mesa Formation to the type section of the Hueco Group in the Hueco Mountains of West Texas, ~75 km south of Otero Mesa? Bachman and Hayes (1958, p. 698, fig. 5) proposed a correlation southward in which the Lee Ranch Tongue is stratigraphically below the Deer Mountain Red Shale Member of the Hueco Group section in the Hueco Mountains, but presented no data to support this correlation, other than stating that they regard a Lee Ranch-Deer Mountain correlation as "arbitrary." However, I regard a Lee Ranch-Otero Mesa-Deer Mountain correlation as a very defensible event-stratigraphic correlation, given that all other red bed "tongues" of the Abo lithosome in the upper part of the Hueco Group apparently are correlative (Lucas et al., 2011a, b). Indeed, the Lee Ranch-Deer Mountain correlation is widely accepted (e.g., King and King, 1929; King, 1942; Pray, 1954, 1961; Pray and Otté, 1954; Thompson, 1954; Otté, 1959; Williams, 1963).

Correlation of the Lee Ranch, Otero and Deer Mountain red beds is the most parsimonious event-stratigraphic correlation. It posits only one red-bed interval in the upper Abo, lower Yeso and upper Hueco lithosomes, all of late Wolfcampian age, from the Sacramento Mounatins to the Hueco Mountains (Fig. 7).

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