TRIASSIC STRATIGRAPHY, BIOSTRATIGRAPHY AND CORRELATION IN EAST-CENTRAL NEW MEXICO

SPENCER G. LUCAS[1], ANDREW B. HECKERT[2] AND ADRIAN P. HUNT[3]
[1]New Mexico Museum of Natural History, 1801 Mountain Rd NW, Albuquerque, NM 87104;
[2]Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131-1116;
[3]Mesalands Dinosaur Museum, Mesa Technical College, 911 South Tenth Street, Tucumcari, NM 88401

Abstract.—Triassic strata in east-central New Mexico are siliciclastic red beds of Middle and Late Triassic age. As much as ~500 m thick, the Triassic section is assigned to the Middle Triassic Moenkopi Formation (Anton Chico Member) and overlying Upper Triassic Chinle Group (Santa Rosa, Garita Creek, Trujillo, Bull Canyon and Redonda Formations). The Anton Chico Member of the Moenkopi Formation is as much as 46 m thick and is mostly trough crossbedded micaceous litharenite. It disconformably overlies Middle Permian red beds of the Artesia Group, and is disconformably overlain by the Upper Triassic Santa Rosa Formation. The Santa Rosa Formation consists of three members: (1) basal, Tecolotito Member, as much as 34 m thick and mostly grayish-orange, trough crossbedded and ripple laminated quartzarenite; (2) medial, Los Esteros Member, as much as 44 m thick and mostly red-bed mudstone; and (3) upper, Tres Lagunas Member, as much as 46 m thick and mostly orange and yellowish brown, crossbedded quartzarenite. The Garita Creek Formation conformably overlies the Tres Lagunas Member and is as much as 76 m thick and mostly red-bed mudstone. It is disconformably overlain by the Trujillo Formation, a medial sandstone complex of the Chinle Group as much as 68 m thick. The Bull Canyon Formation conformably overlies the Trujillo and is as much as 110 m thick and mostly red-bed mudstone. We name a new unit in the Bull Canyon Formation, the Saladito Point Bed, for a discrete, laterally persistent sandstone 12.2 m thick and approximately 30 m above the base of the formation. The Bull Canyon Formation is disconformably overlain by the Redonda Formation, which is up to 92 m thick and mostly laterally continuous, repetitive beds of red-bed sandstone and siltstone. The Middle Jurassic Entrada Sandstone disconformably overlies the Redonda Formation, although the Triassic section is also erosionally truncated locally by younger units throughout east-central New Mexico.

The Anton Chico Member of the Moenkopi Formation correlates with the uppermost Holbrook Member of the Moenkopi Formation in eastern Arizona. The occurrence of the capitosaurid amphibian *Eocyclotosaurus* in the Anton Chico Member indicates a Perovkan (Anisian) age. The erosional surface at the base of the Moenkopi Formation in east-central New Mexico is a compound unconformity corresponding to the Tr-0, Tr-1 and Tr-2 unconformities of earlier authors.

Chinle Group strata in east-central New Mexico correlate readily to the Chinle lithosome in West Texas, Oklahoma, Colorado and across the Colorado Plateau. These strata define three major sequences, in ascending order: the Shinarump-Blue Mesa (Santa Rosa-Garita Creek), Moss Back-Owl Rock (Trujillo-Bull Canyon) and Rock Point (Redonda) sequences. Unconformities at the base of the Santa Rosa, Trujillo and Redonda Formations correspond to the Tr-3, Tr-4, and Tr-5 unconformities, respectively. A lower-order sequence boundary may be present in the Chinle, expressed as a regionally persistent, planar-crossbedded litharenite exposed in east-central New Mexico (Saladito Point Bed), western New Mexico (Perea Bed) and in east-central Arizona at the Petrified Forest National Park (Flattops 2 and Painted Desert 3 sandstones).

Numerous lines of biostratigraphic evidence, principally tetrapod fossils, but also including megafossil plants, ostracodes and invertebrates, constrain the ages of Upper Triassic strata in east-central New Mexico and support the correlations advanced here. These indicate that the Tecolotito Member of the Santa Rosa Formation is of Otischalkian (early-late Carnian) age, and the Los Esteros and Tres Lagunas members and the Garita Creek Formation are of Adamanian (latest Carnian) age. The Tr-4 unconformity approximates the Carnian-Norian boundary, and the Trujillo and Bull Canyon Formations are of Revueltian (early-mid Norian) age. The Redonda Formation is of Apachean (late Norian-Rhaetian) age. The type Revueltian fauna is known from the Bull Canyon Formation in Revuelto Creek, and the type Apachean fauna is the vertebrate fauna of the Redonda Formation in Apache Canyon, both in Quay County.

INTRODUCTION

Exposures of Triassic strata in east-central New Mexico (San Miguel, Harding, Guadalupe, DeBaca, Roosevelt and Quay Counties) form the single largest outcrop belt of Triassic rocks in New Mexico (Fig. 1). These rocks are nonmarine siliciclastic red beds of Middle and Late Triassic age with a maximum thickness of ~500 m. Here, we review the lithostratigraphy, biostratigraphy and biochronology of these rocks to present a comprehensive correlation of the Triassic strata in east-central New Mexico.

PREVIOUS STUDIES

Marcou (1858) first identified Triassic strata in east-central New Mexico as the "New Red Sandstone" or "Keuper." He did so because these rocks underlie strata he considered Jurassic (Middle Jurassic Entrada through Lower Cretaceous Mesa Rica formations of current usage) and because the Triassic red beds resemble the nonmarine Triassic red beds of the Keuper in Germany and France.

Little new information on the Triassic of east-central New Mexico appeared until Darton (1922, 1928) used the name Santa Rosa Sandstone (it had actually first been used by Rich, 1921) to refer to the lower part of the Triassic section and "Chinle?" to the upper (Fig. 2). Regional geologic mapping by the U.S. Geological Survey in the 1940s (Gorman and Robeck, 1946; Dobrolvolny et al., 1946) substantiated Darton's broad divisions and further subdivided the Santa Rosa and Chinle Formations (Fig. 2). Griggs and Read (1959) reflected the Survey's conclusions, assigning the Triassic section in east-central New Mexico to the Santa Rosa, Chinle and Redonda Formations.

Kelley (1972a, b) mapped Triassic strata across much of Guadalupe and DeBaca counties and adjacent areas, proposing largely informal, but readily mappable, subdivisions of the Triassic rocks. At the same time, Gregory (1972) summarized the results of fossil collecting in Triassic strata in east-central New Mexico. This work dated back to the initial explorations of Case (1914) and demonstrated that substantial assemblages of Triassic fossil vertebrates were present in east-central New Mexico (also see Long and Murry, 1995 and Hunt, 1994, 1997a for reviews of the history

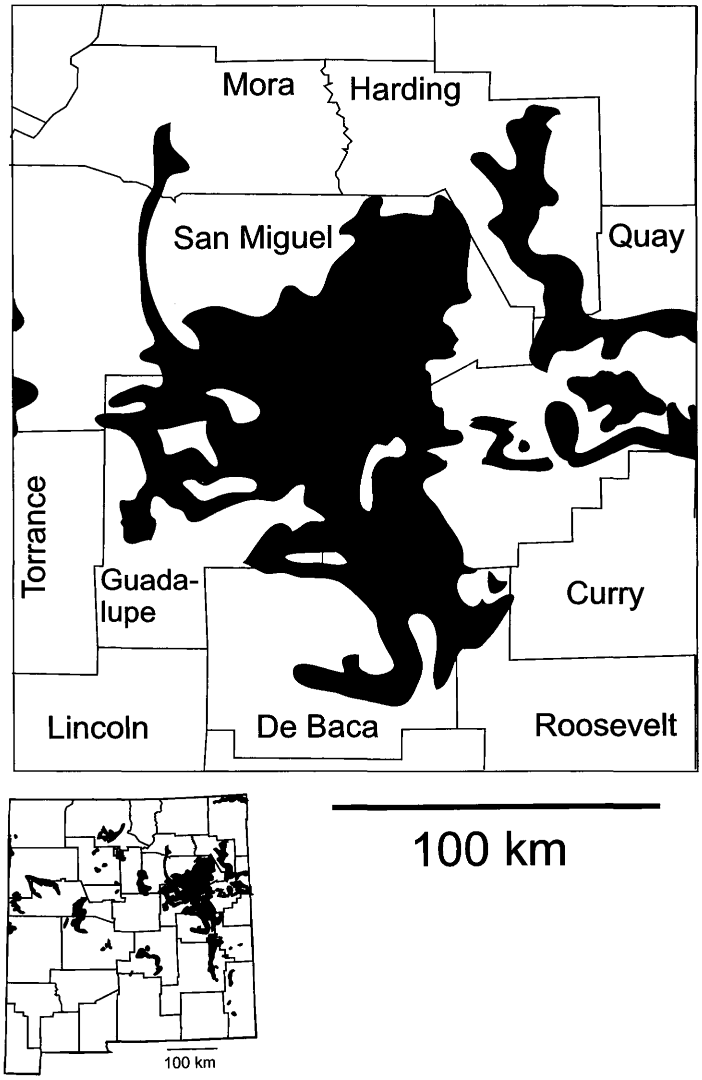

FIGURE 1. Index map showing the distribution of Triassic strata in east-central New Mexico.

of vertebrate fossil collecting in east-central New Mexico).

The 1980s-1990s saw an unprecedented explosion of knowledge of the Triassic of east-central New Mexico. These studies encompassed surface (Lucas et al., 1985a, 1994; Lucas and Hunt, 1987, 1989) and subsurface (Broadhead, 1984, 1985) stratigraphy, sedimentology (Granata, 1981; McGowan et al., 1983; Hester, 1988; Newell, 1993) and paleontological studies, including studies of invertebrate micro- and macrofossils, megafossil plants and vertebrate body and trace fossils (Table 1). This work has reshaped our understanding of Triassic stratigraphy, biostratigraphy and correlation in east-central New Mexico.

LITHOSTRATIGRAPHY

The Triassic section in east-central New Mexico (Fig. 3) has a maximum thickness of ~500 m. These strata are assigned to the Moenkopi Formation (Anton Chico Member) and overlying Chinle Group (Santa Rosa, Garita Creek, Trujillo, Bull Canyon and Redonda formations). The base of the Triassic section is a compound unconformity equivalent to the Tr-0 through Tr-2 unconformities of Pipiringos and O'Sullivan (1978). The erosional surface associated with the Tr-3 unconformity separates the Moenkopi from the overlying Chinle, and the Tr-4 and Tr-5 unconformities of Lucas (1993) are expressed as erosional surfaces beneath the Trujillo and Redonda formations, respectively. Where complete, the section is overlain by the Middle Jurassic Entrada Sandstone (a compound unconformity equivalent to the J-0 through J-2 unconformities of Pipiringos and O'Sullivan, 1978), although post-Jurassic erosion has locally truncated the section.

MOENKOPI FORMATION

The oldest Triassic strata in east-central New Mexico are assigned to the Anton Chico Member of the Moenkopi Formation of Lucas and Hunt (1987). As much as 46 m thick, the Anton Chico Member is mostly grayish-red and moderate reddish-brown, trough crossbedded micaceous litharenite; minor lithologies are red-bed mudstone, siltstone and intraformational conglomerate (Lucas and Hunt, 1987; Lucas and Hayden, 1991; Boy et al., 2001). The Anton Chico Member overlies red-beds of the Middle Permian (Guadalupian) Artesia Group at a substantial disconformity. Typically, the base of the Anton Chico Member is a conglomerate of Artesia Group rip-ups or a coarse sandstone that is color mottled and preserves root traces that are evidence of pedogenesis. This unconformity corresponds to the Tr-2 unconformity (and, by inference, the underlying Tr-1 and Tr-0 unconformities) of Pipiringos and O'Sullivan (1978). The base of the Tecolotito Member of the Santa Rosa Formation above the Anton Chico Member is also a substantial unconformity, the Tr-3 unconformity of Pipiringos and O'Sullivan (1978).

The Anton Chico Member is well exposed in the Sangre de Cristo front range and in the canyons of the Pecos River and its tributaries (Lucas et al., 1990; Lucas and Hayden, 1991; Boy et al., 2001). These outcrops extend as far southeast as Alamogordo Reservoir just north of Fort Sumner in DeBaca County (Lucas and Anderson, 1993). Figure 4 (also see the Appendix) illustrates a characteristic section of the Moenkopi Formation near Puerta de Luna in the Pecos River drainage in Guadalupe County.

The subsurface extent of the Anton Chico Member is more difficult to determine because it and the overlying, sandstone-dominated Tecolotito Member of the Santa Rosa Formation are not readily distinguished from each other on geophysical logs (Broadhead, 1984, 1985; Lucas and Hunt, 1987). In east-central New Mexico, the Anton Chico Member yields fossil plants and vertebrates (see below).

SANTA ROSA FORMATION

The lowermost part of the Chinle Group in east-central New Mexico is the Santa Rosa Formation, consisting of three members (in ascending order): Tecolotito, Los Esteros and Tres Lagunas. The Tecolotito Member disconformably overlies Moenkopi or older strata throughout most of east-central New Mexico, and the Tres Lagunas Member is conformably overlain by the Garita

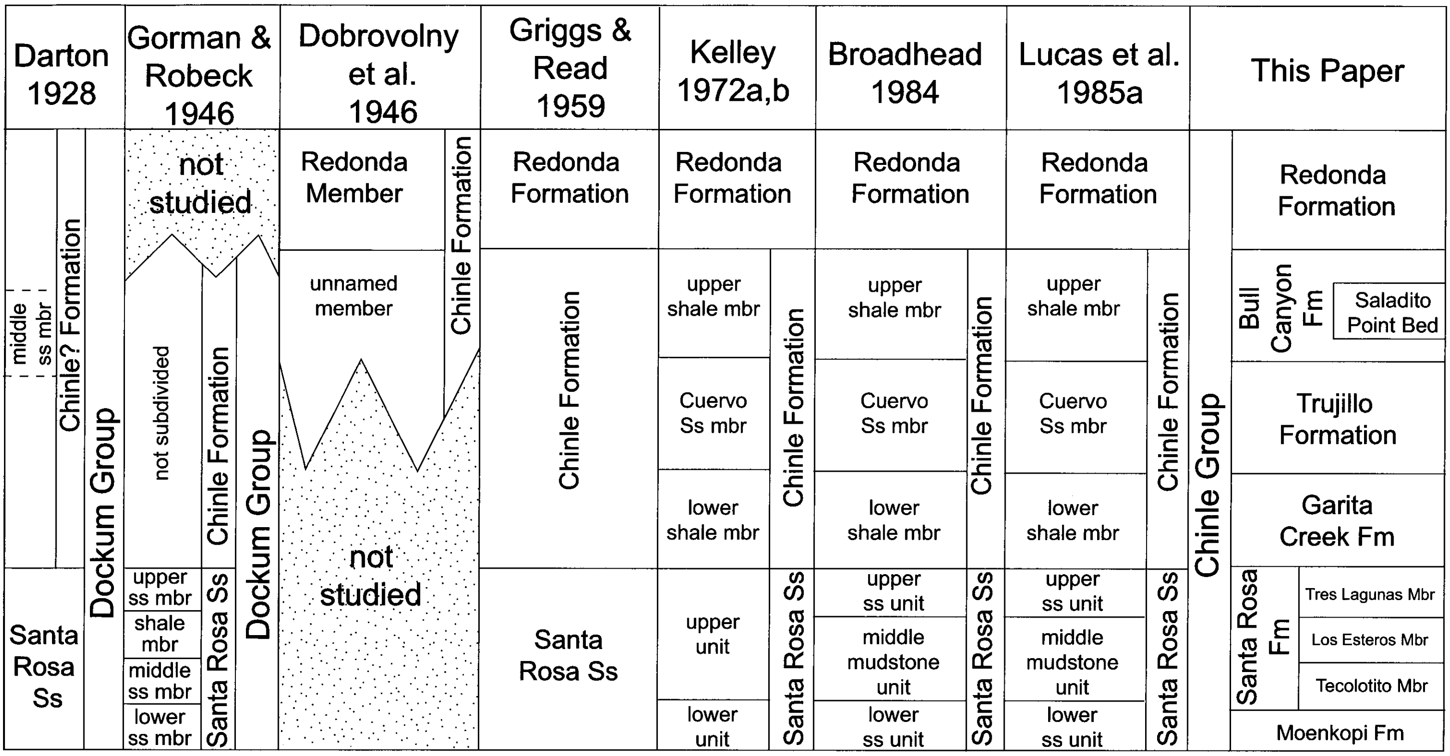

FIGURE 2. Nomenclature chart showing the evolution of Triassic stratigraphic nomenclature in east-central New Mexico.

Creek Formation in this area. The informal name "Canyon Sandstone" (Matthes, 1936) has been used for strata that clearly pertain to the Santa Rosa Formation (Fig. 5), and should be abandoned.

TECOLOTITO MEMBER

The basal interval of the Santa Rosa Formation is the Tecolotito Member of Lucas and Hunt (1987). It is as much as 34 m thick and consists mostly of grayish-orange to very pale orange, trough-crossbedded and ripple-laminated quartzarenite and lesser amounts of extrabasinal (mostly Paleozoic limestone, lithic and siliceous pebbles) conglomerate. The Tecolotito Member has a sharp, disconformable contact on the underlying Moenkopi Formation but grades upward into the overlying Los Esteros Member.

Outcrops of the Tecolotito Member in east-central New Mexico are confined to the canyon country of the Pecos River in Guadalupe and San Miguel counties and the hogbacks along the Sangre de Cristo front range in San Miguel County. The unit has a broad subsurface distribution; it is most of Broadhead's (1984) "lower sandstone unit" of the Santa Rosa Formation. However, the Tecolotito Member does not crop out in the Canadian River near Logan in Quay County (*contra* Finch et al., 1976; Finch and Wright, 1983; Lucas and Hunt, 1987). No fossils other than nondescript petrified wood have been identified in the Tecolotito Member.

TABLE 1. Paleontologic, biostratigraphic, and biochronologic studies of the Triassic in east-central New Mexico since 1985.

Plants: Ash, 1988, 1989 Lucas et al., 1985d Lucas, 2001 **Calcareous microfossils:** Kietzke, 1987, 1989 **Molluscs:** Good, 1989, 1993a,b, 1998 Kues, 1985 **Fish:** Huber et al., 1993 Hunt, 1997b	**Tetrapods (general):** Boy et al. (2001) Carpenter and Parrish, 1985 Parrish and Carpenter, 1986 Lucas et al., 1985b,c Hunt, 1991, 1994, 2001a, b Hunt and Lucas, 1989, 1993a, b, 1997 Long and Murry, 1995 Murry, 1986, 1989 Hunt et al., 1989b Lucas et al., 1998 **Amphibians:** Hunt, 1989a, 1993, 1994 Hunt and Lucas, 1993b Lucas and Morales, 1985	**Phytosaurs:** Ballew, 1989 Hunt, 1989b,c 1994 Hunt and Lucas, 1993c Heckert et al., 2001 **Aetosaurs:** Heckert and Lucas, 1998 Heckert et al., 1996 Hunt and Lucas, 1991a Hunt et al., 1993b **Dinosaurs:** Carpenter, 1997 Heckert et al., 2000 Hunt, 1989c Hunt and Lucas, 1994 Hunt et al, 1998	**Cynodonts:** Lucas and Oakes, 1988 Lucas et al., 1999b **Tetrapod biostratigraphy:** Hunt and Lucas, 1993a, 1997 Lucas and Hunt, 1993 Lucas, 1997, 1998 Murry, 1986, 1989 Parrish, 1989 **Vertebrate Trace Fossils:** Cotton et al., 1997, 1998 Hunt et al., 1989a, 1993a, 2000 Hunt and Lucas, 2001 Lockley and Hunt, 1995, 199[illegible] Lockley et al., 2000

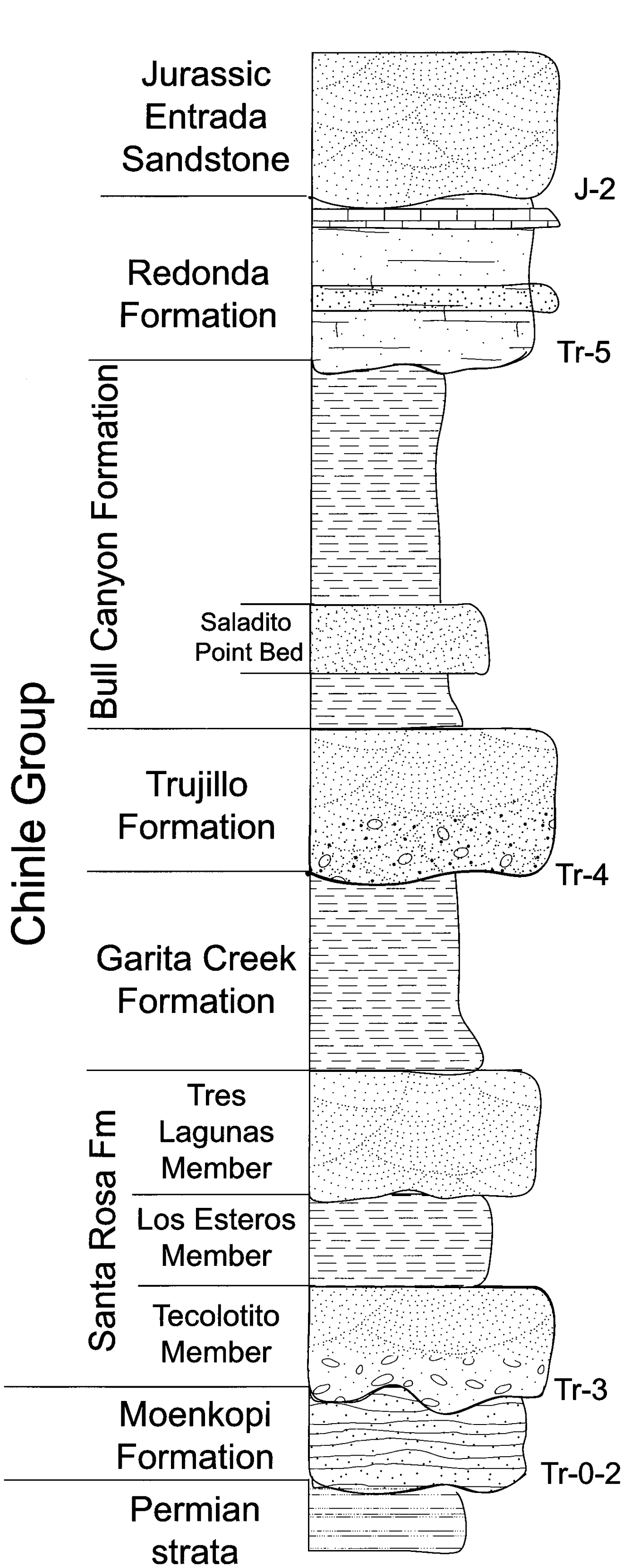

FIGURE 3. Schematic stratigraphic section showing generalized thickness and lithology of Triassic strata in east-central New Mexico.

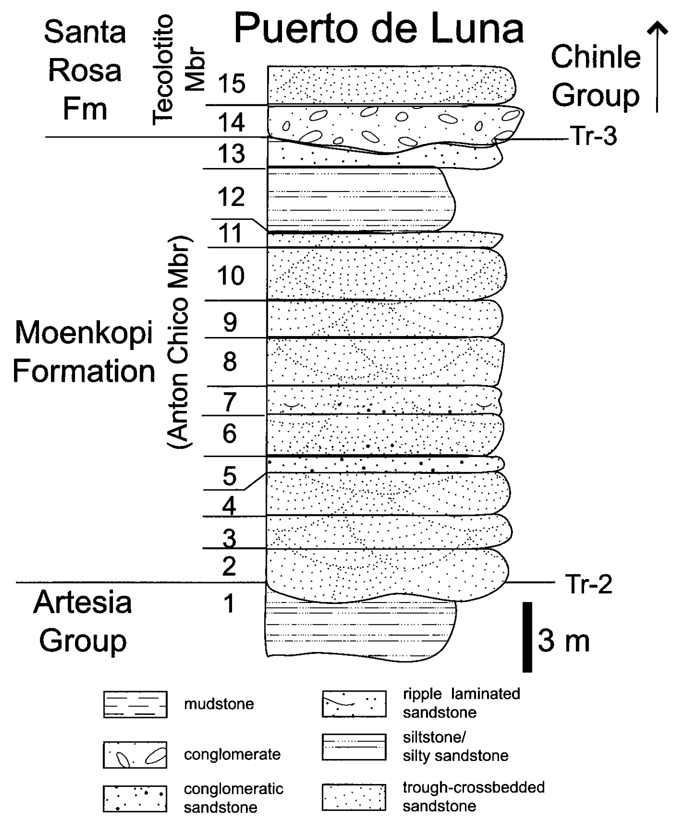

FIGURE 4. Measured stratigraphic section of the Moenkopi Formation near Puerto de Luna. See Appendix for precise location and description of numbered lithologic units.

LOS ESTEROS MEMBER

The medial member of the Santa Rosa Formation in east-central New Mexico is the Los Esteros Member of Lucas and Hunt (1987). The Los Esteros Member ranges in thickness from 0 to 44 m thick in this region. This unit is mostly mudstone and fine sandstone that forms a conspicuous slope between the ledge/cliff-forming Tecolotito (below) and Tres Lagunas (above) members. Mudstones of the Los Esteros Member are mostly reddish brown, but yellowish-brown and purplish-brown bands are also present. Sandstones are very fine- to fine-grained quartzarenites that are usually ripple-laminated or massive. The base of the Los Esteros Member is conformable, with typical Los Esteros mudstones thinly interbedded with sandstones of the upper part of the Tecolotito Member, or Tecolotito sandstones fining upward and/or grading upward into the Los Esteros Member.

In contrast, the contact of the Los Esteros Member with the overlying Tres Lagunas Member is an erosional unconformity. Thus, a thin limestone-pebble conglomerate is commonly present at the base of the Tres Lagunas Member, sharply overlying mudstone or very fine-grained sandstone of the Los Esteros Member. Local relief on this sharp surface is usually as much as 0.3 m (Lucas and Hunt, 1987, fig. 4). Indeed, at some locations (e.g., just north of Los Esteros Reservoir), the Los Esteros Member is absent, and the Tres Lagunas Member rests directly on the Teco-

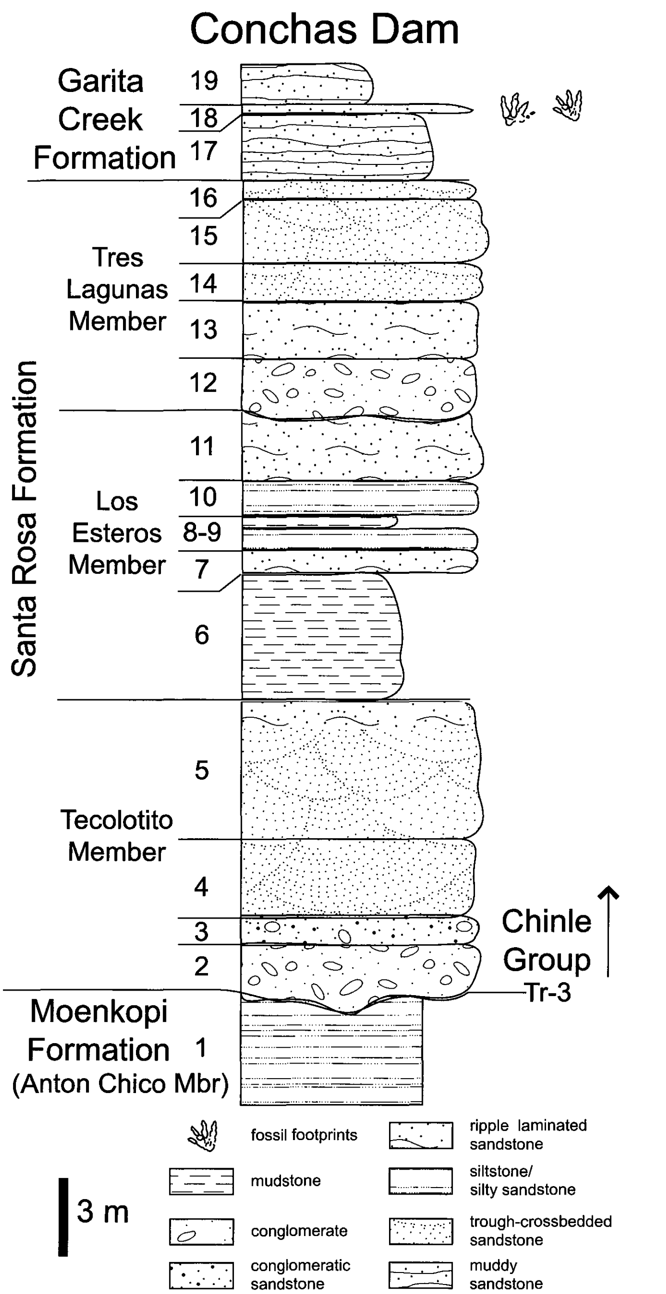

FIGURE 5. Measured stratigraphic section of the lower Chinle Group at Conchas Dam. See Appendix for precise location and description of numbered lithologic units.

lotito Member (Gorman and Robeck, 1946; Kelley, 1972b; Lucas and Hunt, 1987).

The outcrop belt of the Los Esteros Member parallels that of the underlying Tecolotito Member and is confined to the Pecos River valley and the Sangre de Cristo front range (Gorman and Robeck, 1946; Lucas and Hunt, 1987; Lucas et al., 1990). It has a much broader distribution in the subsurface, and corresponds to the informal "middle" member of the Santa Rosa Formation of Broadhead (1984). Fossil plants and vertebrates are known from the Los Esteros Member (see below).

TRES LAGUNAS MEMBER

The upper member of the Santa Rosa Formation in east-central New Mexico is the Tres Lagunas Member of Lucas and Hunt (1987). As much as 46 m thick, it is the most prominent and widely exposed member of the formation, and general perceptions of the Santa Rosa Formation have been based on the Tres Lagunas Member (e.g., Darton, 1928; Kelley, 1972a,b; Broadhead, 1984, 1985). The Tres Lagunas Member is mostly orange and yellowish-brown, medium-grained quartzarenite that displays planar and trough crossbeds and ripple laminae. It disconformably overlies the Los Esteros Member, and its upper contact is a transition from medium-grained quartzarenite to calcareous siltstone of the Garita Creek Formation.

The Tres Lagunas Member crops out in the Sangre de Cristo Front range, and throughout the Pecos River valley (Gorman and Robeck, 1946; Lucas and Hunt, 1987; Lucas et al., 1990). Its subsurface distribution extends eastward into Quay and Curry counties, but it is not present east of Clovis (Broadhead, 1984, fig. 9). No fossils are known from the Tres Lagunas Member other than petrified wood.

"CANYON SANDSTONE"

When Conchas Dam was built in the 1930s, the sandstone-dominated interval the dam was anchored in was referred to as the "Canyon Sandstone" (Matthes, 1936). Spiegel (1972) correlated this sandstone interval to the Trujillo Formation of West Texas, which is in the middle of the Chinle Group, but most workers (e.g., Griggs and Hendrickson, 1951; Wanek, 1962; Dane and Bachman, 1965; Kelley, 1972a; Lucas et al., 1985a) assigned it to the Santa Rosa Formation. Indeed, as Lucas et al. (2001b) demonstrate, all three members of the Santa Rosa Formation make up the "Canyon Sandstone" (Fig. 5). Surprisingly, Fritz (1991, p. 110) concluded that "it is not possible to determine whether or not the 'Canyon Sandstone' represents a member of the Santa Rosa Formation."

Nevertheless, that determination can be made in two ways: (1) a detailed measured section (Fig. 5, Appendix) reveals the characteristic lithologies, succession of lithologies and thicknesses of the three members of the Santa Rosa Formation at Conchas Dam; and (2) the succession of Triassic lithostratigraphic units above the "Canyon Sandstone," well exposed just east of the dam up to La Cinta Mesa (cf. Kelley, 1972a, fig. 1) is Garita Creek, Trujillo, Bull Canyon and Redonda formations, thus establishing that the "Canyon Sandstone" is the Santa Rosa Formation. The problem of correlation of the "Canyon Sandstone" created by Matthes (1936) and perpetuated by Spiegel (1972) and Fritz (1991) is thus readily solved by detailed stratigraphy. Obviously, the term "Canyon Sandstone" is superfluous and should be abandoned.

"LOGAN SANDSTONE"

Trauger et al. (1972) applied the name "Logan Sandstone" to the sandstone interval in which Ute Dam, near Logan in Quay County, is anchored. They did so because of uncertainty as to whether this sandstone represents the Santa Rosa Formation (Dane and Bachman, 1965; Finch et al., 1976; Finch and Wright, 1983) or the Trujillo Formation (Spiegel, 1972; Trauger et al., 1972). However, as Lucas et al. (1985a) noted, the "Logan Sandstone" is readily traced approximately 50 km eastward to Trujillo Camp, in West Texas, which is the type section of the Trujillo Formation of Gould (1907). "Logan Sandstone" thus is a synonym of Trujillo Formation.

GARITA CREEK FORMATION

Kelley (1972a,b) used the term "lower shale member of Chinle Formation" to refer to the mudstone-dominated interval of the Chinle Group immediately above the Tres Lagunas Member of the Santa Rosa Formation. Lucas and Hunt (1989) coined the term "Garita Creek Member" for this interval and designated a type section in the drainage of Garita Creek. As much as 76 m thick, the Garita Creek Formation is mostly grayish-red and moderate brown mudstone and lesser amounts of grayish-red, laminar sandstone and thin intraformational conglomerate. The unit typically forms a slope between the cliff/bench-forming Tres Lagunas Member of the Santa Rosa Formation (below) and the Trujillo Formation (above).

Garita Creek Formation outcrops are found throughout much of east-central New Mexico, especially along the Canadian Escarpment of San Miguel and Guadalupe Counties, and in the Pecos River drainage as far south as Fort Sumner. As stated above, the base of the Garita Creek Formation is conformable on the Tres Lagunas Member of the Santa Rosa Formation. The base of the Trujillo Formation overlying the Garita Creek is an unconformity (see below). Vertebrate fossils from the Garita Creek Formation are discussed below.

TRUJILLO FORMATION

As early as the 1920s, Darton (1928) recognized a persistent medial sandstone interval in Chinle Group strata in east-central New Mexico. Gould (1907) had named these strata the Trujillo Formation of the Dockum Group in West Texas, and Kelley (1972b) named them the Cuervo Sandstone Member of the Chinle Formation in east-central New Mexico. They are now assigned to the Trujillo Formation of the Chinle Group (Lucas and Hunt, 1989; Lucas, 1993, 1995). In east-central New Mexico, the Trujillo Formation is as much as 68 m thick and consists mostly of yellowish-gray, light olive gray and greenish-gray micaceous sandstone with lenses and beds of intrabasinal conglomerate and red-bed mudstone. Planar and trough crossbeds are the dominant bedforms. The clasts in Trujillo conglomerates are almost entirely rip-ups of pedogenic calcrete from underlying Chinle mudrocks.

The Trujillo Formation has a sharp, scoured and disconformable contact on the underlying Garita Creek Formation. Typically, Trujillo sandstone or conglomerate rests directly on Garita Creek mudstone at a sharp surface with up to 1 m of stratigraphic relief locally. Lucas (1993) identified the base of the Trujillo Formation in east-central New Mexico as the Tr-4 unconformity, a pervasive unconformity throughout the Chinle depositional basin. The Trujillo Formation is conformably overlain by the Bull Canyon Formation (see below).

The Trujillo Formation crops out extensively in east-central New Mexico, especially along the Canadian Escarpment in San Miguel and Guadalupe Counties and in the Canadian River drainage from Newkirk in Guadalupe County to Ute Dam in Quay County. The Trujillo Formation typically is a cliff-or bench-forming complex of sandstone/conglomerate bodies and intercalated mudrock that defends mesas and escarpments. Indeed, in east-central New Mexico, some of the flat geomorphic surfaces beneath badlands developed in the Bull Canyon Formation, such as the broad flats from Tucumcari to San Jon in Quay County, are underlain by the Trujillo Formation. In the subsurface, the Trujillo Formation extends eastward into West Texas (Broadhead, 1984, 1985).

A sparse, but age-diagnostic vertebrate fauna is known from the Trujillo Formation (Hunt, 2001a; also see below). Palynomorphs and megafossil plants have also been collected from the Trujillo Formation, principally in Texas (Ash, 1976; Dunay and Fisher, 1974, 1979; Litwin et al., 1991; Cornet, 1993).

BULL CANYON FORMATION

Kelley (1972a,b) used the term "upper shale member of Chinle Formation" to refer to the mudrock-dominated unit above the Trujillo Formation in east-central New Mexico. Lucas and Hunt (1989) named this unit the Bull Canyon Formation. In West Texas, the same unit had been included, in part, in the Trujillo Formation by Gould (1907) and referred to in its entirety as the Chinle Formation by Adams (1929), Adkins (1932) and Reeside et al. (1957). However, Chatterjee (1986) named this unit the Cooper Member of the Dockum Formation, failing to describe a type section and overlooking the fact that Cooper was a preoccupied name, having long been used as a stratigraphic term in South Carolina (Lucas et al., 1994).

Despite this, Lehman et al. (1992) renamed Chatterjee's Cooper Member the "Cooper Canyon Formation" and subsequently (Lehman, 1994) claimed that this name had priority over the Bull Canyon Formation of Lucas and Hunt (1989). The rule of priority, however, would require that Bull Canyon Formation has precedence as the lithostratigraphic name for the formation that immediately overlies the Trujillo Formation in east-central New Mexico and West Texas (Lucas et al., 1994).

In east-central New Mexico, the Bull Canyon Formation is as much as 110 m thick and is mostly grayish-red and moderate reddish-brown mudstone and lesser amounts of yellowish-gray to grayish-red, laminar to trough-crossbedded litharenite. Very minor lithologies are siltstone and intraformational conglomerate. The Bull Canyon Formation has a conformable, even intertonguing, relationship with the uppermost portion of the underlying Trujillo Formation (Granata, 1981; McGowan et al., 1983; Lucas and Hunt, 1989). The Redonda Formation overlies the Bull Canyon Formation throughout east-central New Mexico, and this contact has been described as conformable (Dobrovolny et al., 1946; Griggs and Read, 1959; Lucas et al., 1985a) or unconformable (Kelley, 1972a; Granata, 1981; Hester, 1988; Lucas, 1993; Hester and Lucas, 2001). We note the sharp lithologic con-

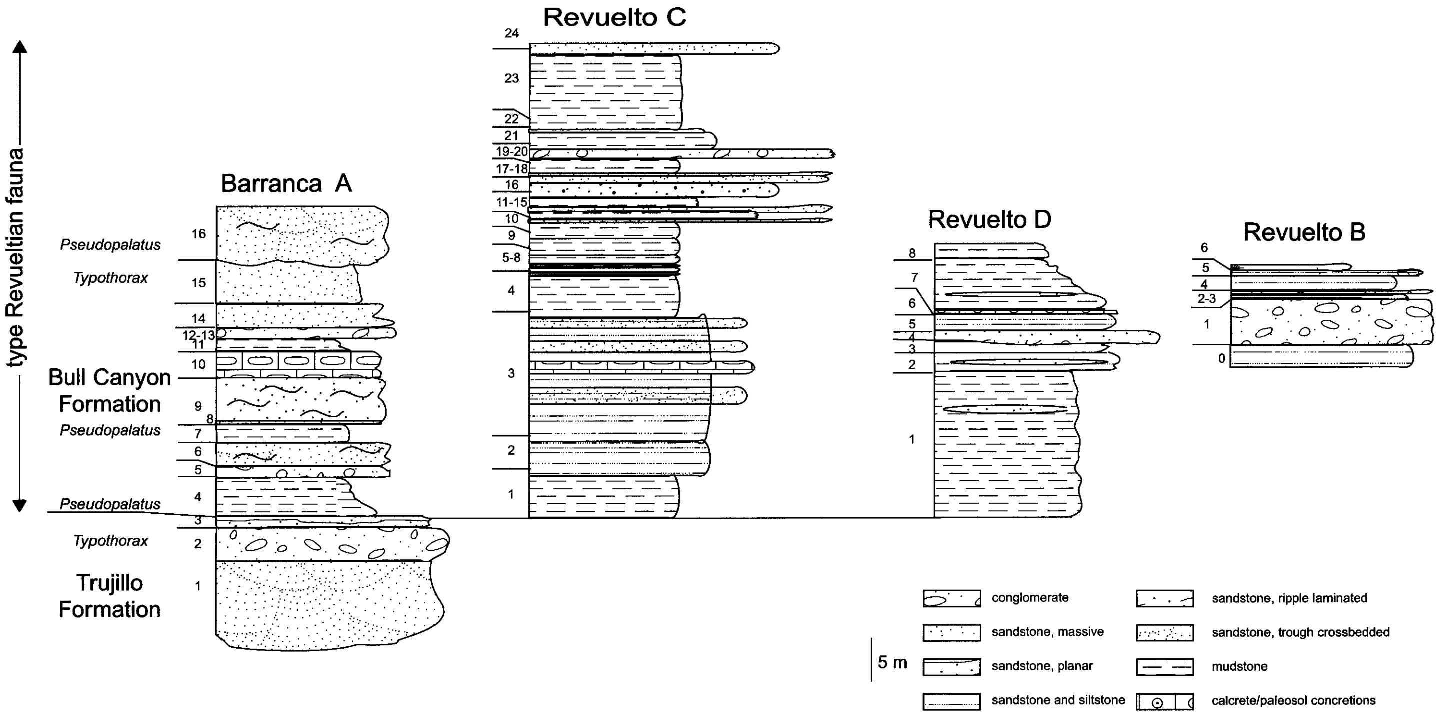

FIGURE 6. The stratigraphic range of the type Revueltian vertebrate assemblage is evident in measured stratigraphic sections of the Trujillo and Bull Canyon formations in the Barranca Creek (section A) and Revuelto Creek (sections B-D) drainages southeast of Tucumcari, Quay County. See Appendix for precise location and description of numbered lithologic units.

trast and change in depositional style that characterizes the Bull Canyon-Redonda contact, features well documented by Hester (1988), to conclude that the contact is disconformable. Indeed, for this reason, Lucas (1993) identified the base of the Redonda Formation as an unconformity, and based on the correlations of bracketing strata, identified it as the basinwide Tr-5 unconformity of the Chinle Group.

The Bull Canyon Formation crops out extensively in east-central New Mexico, especially along the Canadian Escarpment and Llano Estacado. Here, it forms mudstone-dominated slopes between the cliff/bench-forming Trujillo Formation (below) and the ledgy, repetitively-bedded Redonda Formation (above). Fossils of charophytes, land plants, ostracodes, unionids and vertebrates are present in the Bull Canyon Formation, including the type Revueltian fauna of Lucas and Hunt (1993) (Fig. 6), discussed in more detail below.

SALADITO POINT BED

We identify a persistent, bench-forming sandstone-dominated unit in the lower part of the Bull Canyon Formation as a new bed-level unit, the Saladito Point Bed (Figs. 7-8, Appendix). At its type section, the Saladito Point Bed is 12.5 m thick and is mostly pale reddish-brown, trough-crossbedded litharenite and grayish-red intraformational conglomerate. The bed is named for Saladito Point of Mesa Rica near the type section.

Kelley (1972a, p. 88) first drew attention to the Saladito Point Bed, referring to it as a "particularly well developed brown sandstone sequence 25-75 feet in thickness" and mapped its distribution in the vicinity of Newkirk and Cuervo in Guadalupe County at approximately 1:450,000 scale (Kelley, 1972a, fig. 1). The Saladito Point Bed crops out farther eastward, at least to Montoya in Quay County, and is present in the type section of the Bull Canyon Formation in Bull Canyon, Guadalupe County (Lucas and Hunt, 1989, fig. 3, units 9-10). This persistent, bench-forming unit low in the Bull Canyon Formation thus is of stratigraphic utility and merits formal recognition.

Interestingly, similar sandstone-dominated intervals are also present in correlative strata on the Colorado Plateau in west-central New Mexico and eastern Arizona. Cooley (1957) was the first to recognize this, and informally named a variety of sandstone units (the Chambers, Taaiylone, Zuni River and Perea beds) in the lower Painted Desert Member of the Petrified Forest Formation in west-central New Mexico and east-central Arizona in the drainages of the Little Colorado and Puerco Rivers. Billingsley (1985a,b) identified several persistent sandstone ledges in the Painted Desert Member of the Petrified Forest Formation as the Flattops sandstones (1-4 in ascending order, southern portion of the Petrified Forest National Park) and Painted Desert sandstones (1-2 of Billingsley, 1985a, 1-3 of Billingsley, 1985b) in the northern portion of the Petrified Forest National Park. We recognize Flattops Sandstone 2 and Painted Desert Sandstone 3 of Billingsley (1985b) as possible correlatives of the Saladito Point Bed. Lucas et al. (1997) designated a type section of the Perea Bed low in the Painted Desert Member of the Petrified Forest Formation near Fort Wingate, New Mexico. Although it is lithologically similar, the Correo

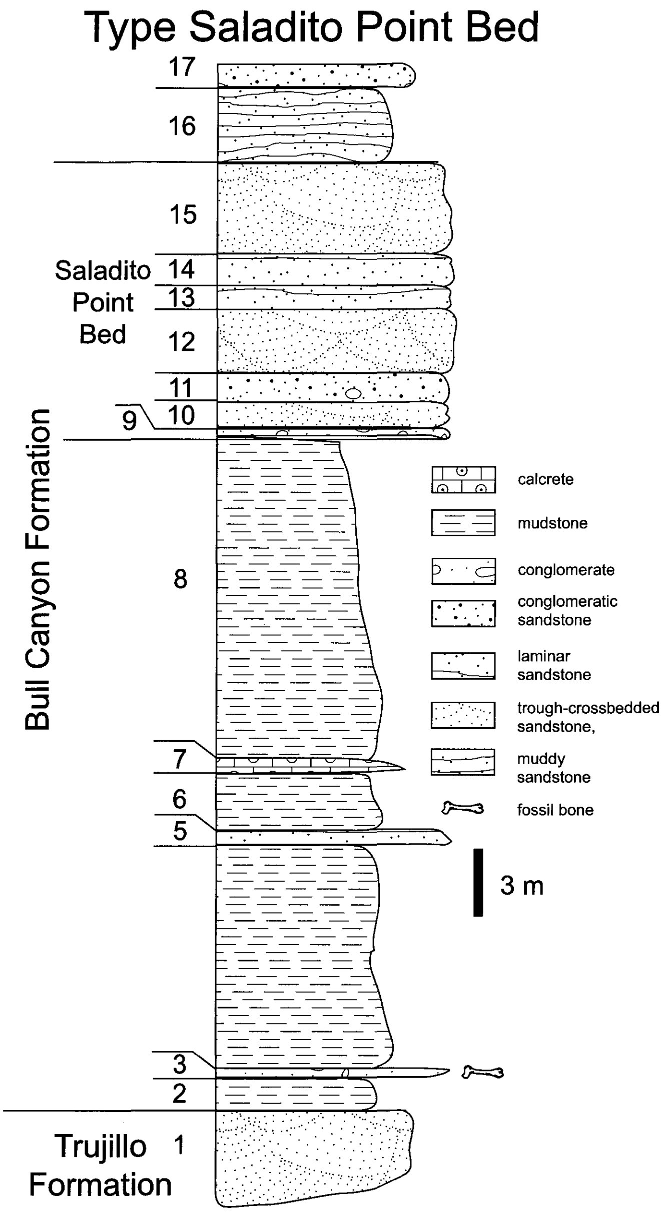

FIGURE 7. Measured stratigraphic section of the lower part of the Bull Canyon Formation at the type section of the Saladito Point Bed. See Appendix for precise location and description of numbered lithologic units.

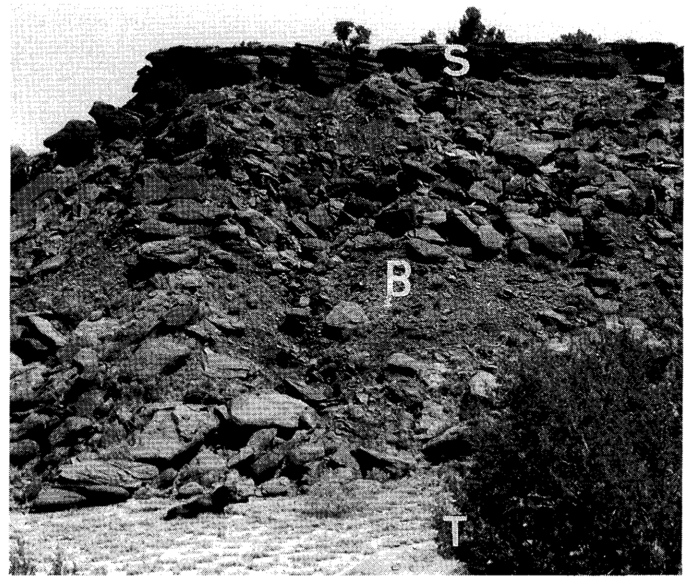

FIGURE 8. Photograph of the type section of the Saladito Point Bed. T = Trujillo Formation, B = Bull Canyon Formation mudstones, S = Saladito Point Bed.

Bed (Lucas and Heckert, 1994) is much higher stratigraphically than these units and is not relevant to discussion here.

The Perea, Flattops 2, Painted Desert 3, Zuni River, Chambers and Taaiylone beds are similar to the Saladito Point bed lithologically and stratigraphically. All occur low in the mudrock-dominated interval of the second sequence of the Chinle Group (Lucas, 1993), either the Painted Desert Member on the Colorado Plateau or the Bull Canyon Formation on the High Plains. Typically, these sandstones are approximately 20-30 m above the highest sandstone of the Sonsela Member (Colorado Plateau) or Trujillo Formation (High Plains) and are 5-15 m thick. Lithologies characteristically are reddish-brown and pale green, planar to trough-crossbedded litharenites with minor intraformational conglomerate dominated by rip-up clasts of bentonitic mudstone and pedogenic calcrete nodules. Espegren (1985) interpreted Flattops Bed 2 as representing the deposits of a high sinuosity fluvial system with bed and suspended loads. Fossils are uncommon in these beds, but locally include abundant bivalves or fragmentary, badly weathered fossil bone. Each of these bed-level units can be traced laterally for km.

Beyond the lithostratigraphic similarity of these beds, note that this apparent outcrop trend, from east-central Arizona to east-central New Mexico, is a transect approximately 45° to 90° to the known depositional dip of the upper Chinle sediments based on numerous northerly paleocurrents (e.g., Stewart et al., 1972; Dubiel, 1989). This suggests that these regionally persistent sandstones may not simply be localized depositional features. Instead, they may represent an interval of lowered regional base level and subsequent recovery, when the rate of avulsion in Chinle streams was high relative to regional subsidence (accommodation) (e.g., Blakey and Gubitosa, 1984, fig. 5.1).

REDONDA FORMATION

The youngest Triassic strata in east-central New Mexico are assigned to the Redonda Formation of Dobrovolny et al. (1946). The formation is as much as 92 m thick and is laterally continuous, repetitively-bedded fine sandstones, siltstones and mudstones (Hester and Lucas, 2001). These are mostly moderate reddish-brown and form ribbed cliffs and steep slopes. As discussed above, the base of the Redonda Formation is a regional unconformity, and the top of the Redonda Formation is a regional unconformity overlain by Middle Jurassic strata; this is the J-2 unconformity of Pipiringos and O'Sullivan (1978).

The Redonda Formation crops out extensively in east-central New Mexico, particularly along the Canadian Escarpment and

Llano Estacado. Here it forms ledgy, repetitively-bedded slopes above the badlands of the Bull Canyon Formation (below) and cliffs of the Middle Jurassic Entrada Sandstone or, locally, younger strata (above). A diverse vertebrate fauna is known from the Redonda Formation (Gregory, 1972; Huber et al., 1993; Heckert et al., 2001; also see below).

BIOSTRATIGRAPHY AND BIOCHRONOLOGY

Triassic strata in east-central New Mexico yield megafossil plants, calcareous microfossils, unionid bivalves, vertebrate bones and tetrapod tracks (Table 1). Here, we review the stratigraphic distribution of these fossils and discuss their biochronological significance.

Megafossil Plants

No palynological studies have been undertaken in the Triassic strata of east-central New Mexico, but megafossil plants are present in various parts of the section. The stratigraphically lowest megafossil plants are from the Anton Chico Member of the Moenkopi Formation, a monotaxial assemblage of the bennettitalean "*Zamites*" *powellii* (Lucas, 2001). The only substantial Triassic paleofloral assemblage from east-central New Mexico is from the Los Esteros Member of the Santa Rosa Formation (Ash, 1972, 1988). This includes the fern *Cynepteris lasiophora*, the bennettitalean *Zamites powellii*, the conifer *Pelourdea poleoensis* and the *incertae sedis* taxa *Dinophyton spinosus* and *Samaropsis* sp. Stratigraphically higher plant records in the Triassic section in east-central New Mexico are sparse and isolated and include pith casts of *Neocalamites* in the Bull Canyon and Redonda formations and impressions of *Sanmiguelia* in the Bull Canyon Formation (Lucas et al., 1985a, d; Hunt, 1994).

Little is known of Moenkopi plants in the western United States (Ash and Morales, 1993), and the Moenkopi record of "*Zamites*" *powelli* is a substantial stratigraphic range extension of a characteristic Chinle Group plant taxon (Lucas, 2001). The flora from the Los Esteros Member is characteristic of the *Dinophyton* zone of Ash (1980), and this zone is present in Adamanian (upper Carnian) strata of the Chinle Group across a broad area (Lucas, 1997). *Sanmiguelia* from the Bull Canyon Formation is typical of Ash's (1980) *Sanmiguelia* zone, which is widely distributed in Revueltian-Apachean (Norian-Rhaetian) strata of the Chinle Group (Lucas, 1997).

Thus, the paleoflora of the Los Esteros Member indicates an Adamanian age, whereas the one record of *Sanmiguelia* from the Bull Canyon Formation is suggestive of a Revueltian-Apachean age. Much more will have to be known of Triassic fossil plants from east-central New Mexico before they can be of greater biostratigraphic utility.

Calcareous Microfossils

Kietzke (1987, 1989) documented charophytes (*Altochara* and *Stellatochara*), ostracods (*Darwinula* and *Lukevichinella*?) and "spirorbids" from the Bull Canyon and Redonda Formations in east-central New Mexico. These fossils are of limited value to biochronology, largely because their taxonomy is problematic. Nevertheless, Chinle Group records in Arizona of ostracods similar to those from the Bull Canyon and Redonda Formations are in Revueltian-Apachean strata (Lucas, 1997). This lends some weak support to regional correlations of both the Bull Canyon and Redonda formations based on tetrapods (see below).

Unionid Bivalves

Kues (1985) documented an extensive assemblage of unionids from the Bull Canyon Formation in Guadalupe County. Good (1993a,b, 1998) revised Chinle unionids and put them into a biostratigraphic context that demonstrates that they are of little or no biochronological value (also see Lucas, 1993, 1997). At best, the Bull Canyon Formation unionids are consistent with generally greater unionid abundances in the upper Chinle Group when compared to the lower Chinle. However, the taxa present (and note that we are very skeptical of the validity and utility of Good's [1998] Chinle unionid taxonomy) have long stratigraphic ranges in the Carnian-Norian Chinle Group and are not (at the species level) known elsewhere.

Vertebrate Fossils

Fossil vertebrates are found throughout the Triassic section in east-central New Mexico and provide the most robust biostratigraphy and biochronology of these strata. This record has been reviewed at length elsewhere (e.g., Hunt and Lucas, 1993a; Lucas, 1993, 1997, 1998, 2000; Hunt, 1994), so we provide only a brief summary:

1. The Anton Chico Member yields fossils of the temnospondyl *Eocyclotosaurus*, an index fossil of the Perovkan land-vertebrate faunachron (lvf) of early Anisian age (Lucas and Morales, 1985; Lucas and Hunt, 1987; Lucas, 1998, 2000; Boy et al., 2001). Other Moenkopi tetrapods from east-central New Mexico are fragmentary but include a *Stanocephalosaurus*-like temnospondyl (Boy et al., 2001) and a *Shansisuchus*-like erythrosuchid (Lucas et al., 1998), also consistent with a Perovkan age.

2. Santa Rosa Formation strata have not yielded tetrapods in east-central New Mexico other than fragmentary metoposaurid fossils indicative of a Late Triassic age. However, at Lamy in Santa Fe County, the Los Esteros Member yields the aetosaurs *Desmatosuchus haplocerus* and cf. *Stagonolepis wellesi*, an *Ischigualastia*-like dicynodont and the phytosaurs *Angistorhinus* and *Rutiodon*, taxa indicative of an early Adamanian age (Hunt and Lucas, 1995).

3. The Garita Creek Formation in east-central New Mexico yields a sparse tetrapod assemblage that includes *Desmatosuchus haplocerus*. This, and its stratigraphic position, suggest an Adamanian age (Hunt et al., 1989b). Near Lamy in Santa Fe County the Garita Creek Formation also contains the famous amphibian quarry of the temnospondyl *Buettneria perfecta* (Romer, 1939; Colbert and Imbrie, 1956; Hunt, 1993). An additional locality near Lamy yields numerous microvertebrate fossils, including teeth of the dinosaurs *Pekinosaurus olseni* and aff. *Galtonia* (Heckert

et al., 2000). Note also that previous reports of the aetosaur *Typothorax* from the Garita Creek Formation (Hunt et al, 1989b; Hunt and Lucas, 1993a, 1995) are of a new species distinct from the Revueltian (early-mid Norian) taxon *Typothorax coccinarum*. Thus, tetrapod fossils strongly support an Adamanian age for the Garita Creek Formation in east-central New Mexico.

4. Hunt (1991, 2001a) documents the Revueltian index taxa *Typothorax coccinarum* and *Pseudopalatus*-grade phytosaurs from the Trujillo Formation in eastern Quay County.

5. The vertebrate assemblage from the Bull Canyon Formation in east-central New Mexico is the type assemblage of the Revueltian lvf of Lucas and Hunt (1993) and is reviewed at length by Hunt (1994, 2001b).

6. The vertebrate assemblage of the Redonda Formation in east-central New Mexico is the basis of the Apachean lvf of Lucas and Hunt (1993). Huber et al. (1993), Hunt and Lucas (1993a) and Heckert et al. (1996, 2001) review this fauna.

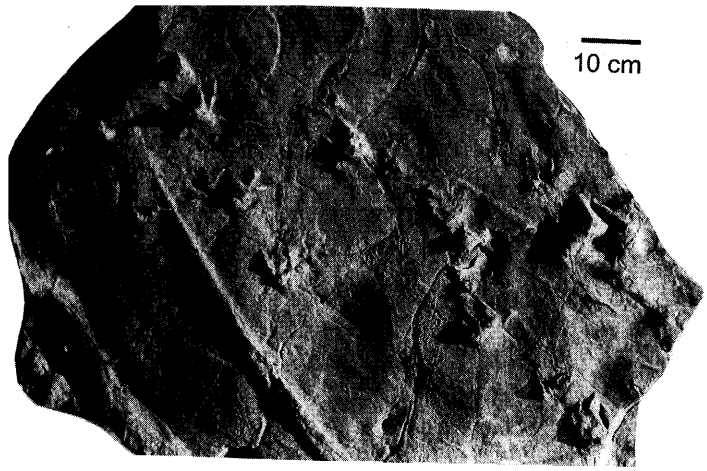

FIGURE 9. Field photograph of the holotype slab of *Barrancapus cresapi.*

Tetrapod Footprints

Only a few tetrapod footprints are known from Triassic strata below the Redonda Formation in east-central New Mexico. These are a track of the ichnogenus *Brachychirotherium* from the Garita Creek Formation (Hunt and Lucas, 2001), and the holotype of the ichnotaxon *Barrancapus cresapi* from the Bull Canyon Formation (Hunt et al., 1993a; Fig. 9).

Barrancapus cresapi was named by Hunt et al. (1993a) for a small, quadrupedal trackway from the lower Bull Canyon Formation (Upper Triassic) of Quay County, New Mexico. The holotype slab (New Mexico Museum of Natural History [NMMNH] P-4782 is a plastotype) from NMMNH locality 55 preserves two parallel-trackways in convex hyporelief preserved in a lenticular, conglomeratic sandstone, which we interpret as representing a low-sinuosity channel with fluctuating discharge (Fig. 9).

The trackways display a range of extramorphological variation. The best preserved pedal impression has a length and width of 60 mm. It is pentadactyl and mesaxonic with broad, tapering digit impressions. The associated manus imprint is 40 mm long and 50 mm wide. This manus impression, as well as at least three others, are markedly entaxonic. The manus impression preserves ?five digit impressions with digit impressions I and V being the longest. *Barrancapus cresapi* is the only named track type from the Revueltian lvf (Norian) strata of western North America. Other tetrapod ichnotaxa from this time interval are restricted to swimming traces of phytosaurs(?) from near the type locality of *Barrancapus* and enigmatic tracks from the Painted Desert Member of the Petrified Forest Formation, Petrified Forest National Park, Arizona. The Painted Desert tracks have mean track (pedal track?) lengths and widths of 63 mm and 58 mm, respectively, which are very similar to values of *Barrancapus cresapi*.

The most notable feature of the morphology of *Barrancapus cresapi* is the large inferred size of digit I and its medial orientation. Among Triassic tetrapods, medial orientation of digit I is most closely matched in prosauropod dinosaurs. Two factors argue against *Barrancapus cresapi* representing a prosauropod: (1) the apparently large, inferred size of digit I; and (2) the hypothesis that the clawed pollex was held off the ground. However, at present it is most parsimonious to assign *Barrancapus cresapi* to the Prosauropoda, but we adopt a conservative approach and consider it as ?Prosauropoda. *Barrancapus cresapi* is the oldest track attributed to a prosauropod dinosaur. Other Revueltian prosauropod occurrences from western North America are limited to isolated specimens from the Bull Canyon Formation of Quay County, New Mexico and Garza County, Texas.

The Redonda Formation has an extensive tetrapod footprint assemblage of low diversity assigned to the ichnogenera *Rhynchosauroides* (rhnychocephalian), *Brachychirotherium* (aetosaur?), *Grallator* (theropod dinosaur) and *Pseudotetrasauropus* (prosauropod dinosaur) (Gregory, 1972; Hunt et al., 1989a, 1993a, 2000; Lockley et al., 2000; Lucas et al., 2001a). These tracks closely resemble other footprint assemblages from the Rock Point Formation of the Chinle Group on the Colorado Plateau, and thus support (but do not demonstrate) a Redonda-Rock Point correlation.

CORRELATION

Lithostratigraphic and biostratigraphic data allow a precise and detailed correlation of Triassic strata in east-central New Mexico to Triassic strata both to the west, in central and west-central New Mexico, and to the east, in West Texas (Fig. 10). Key points of this correlation are:

1. Moenkopi strata are continuous from west-central New Mexico to east-central New Mexico, and vary little in lithology and thickness across this transect. Moenkopi strata are not present in West Texas (Lucas and Anderson, 1992, 1993). Continuity of the Anton Chico Member of the Moenkopi Formation in New Mexico with the Holbrook Member in east-central Arizona can be demonstrated (Lucas and Hayden, 1989), and this further supports a Perovkan age assignment for the Anton Chico Member.

2. The base of the Chinle Group is a pervasive unconformity (Tr-3 unconformity) immediately overlain by an interval of quartzose sandstone and extrabasinal (siliceous) conglomerate referred to the Shinarump, Agua Zarca, Santa Rosa (Tecolotito

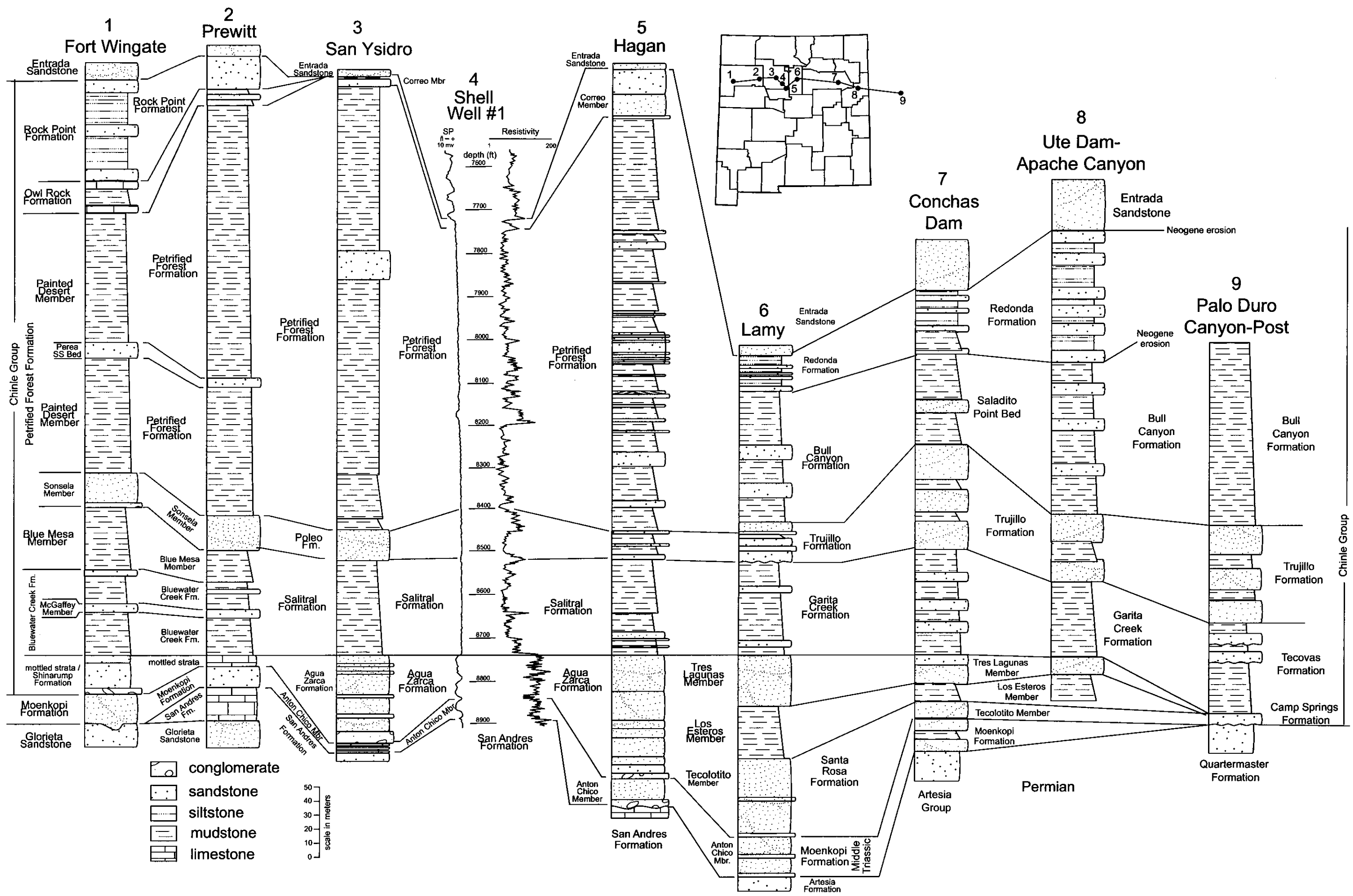

FIGURE 10. Correlation of Triassic strata from west-central New Mexico to West Texas. Sections from Fort Wingate to Lamy from Lucas et al. (1999). Section at Conchas Dam based on Wanek (1962), Lucas and Hunt (1987, 1989) and data presented here. Section at Ute Dam-Apache Canyon based on data in Dobrovolny et al. (1946), Finch et al. (1976) and Hunt (1994). Section at Palo Duro Canyon-Post based on data in Gould (1907), Hunt and Lucas (1991) and Lehman et al. (1992).

Member) and Camp Spring formations. These units are homotaxial and, within resolution, of the same age; note that along the transect depicted here, they are all overlain by units that yield Adamanian-age fossils. In West Texas, the Camp Springs Formation yields the phytosaur *Paleorhinus* and thus is of Otischalkian age (Hunt and Lucas, 1991b). Therefore, it is likely that the basal sandstone/conglomerate unit of the Chinle Group is of Otischalkian age from West Texas to west-central New Mexico.

3. Strata that lie below the Tr-4 unconformity along this transect yield Adamanian-age vertebrates (see below) that correlate them from west-central New Mexico to West Texas.

4. Significantly, the Adamanian section in east-central New Mexico is much thicker than the age equivalent section in West Texas (also see Lucas et al., 1994) or west-central New Mexico (Heckert and Lucas, 1996). The thickness variation between east-central New Mexico and West Texas is perhaps best explained as being controlled by the Frio uplift, a subdued Paleozoic positive that separates east-central New Mexico from West Texas; it is the basin divide between the late Paleozoic Tucumcari and Palo Duro basins (Broadhead, 1984). Thus, Moenkopi strata pinch out and Tecolotito member strata thin across the uplift, and Los Esteros and Tres Lagunas strata also pinch out (Broadhead, 1984, fig. 9). The Tecovas Formation in West Texas thus is apparently physically continuous with the Garita Creek Formation in east-central New Mexico.

In west-central New Mexico, the remnant Paleozoic Zuni uplift played a similar role in limiting the thickness of the Otischalkian-early Adamanian section. Here, the Shinarump Formation and associated "mottled strata" filled paleotopography developed in the Moenkopi Formation during development of the Tr-3 unconformity (Lucas and Hayden, 1989; Heckert and Lucas, 1996). Farther to the west, the Moenkopi Formation thickens again. Notably, Adamanian strata in west-central New Mexico also demonstrate that at least 50 m of strata were removed during the Tr-4 unconformity (Heckert and Lucas, 1996). Thus, structural features at the Chinle basin margin control the thickness of the Otischalkian-early Adamanian section here, and erosion associated with the development of the Tr-4 unconformity explains differences in the thickness of Adamanian strata from west-central to east-central New Mexico.

5. Across the transect (Fig. 10), a pervasive unconformity (Tr-4 of Lucas, 1991, 1993, 1997) underlies a medial Chinle Group

sandstone complex termed Sonsela, Poleo or Trujillo. Fossil vertebrates suggest that these are Revueltian (Norian)-age strata, but palynology in Texas suggests a Carnian age (Dunay and Fisher, 1979). The possibility that this sandstone complex is diachronous should be considered, as should the possibility that the late Carnian palynomorphs, which are from strata bearing intraformational clasts of late Carnian age, are reworked.

6. Thick sections of red-bed mudstones above the medial sandstone complex yield Revueltian-age fossils and are termed Painted Desert, Petrified Forest and Bull Canyon. Thickness variation across this transect (Fig. 10) probably reflects a combination of: (1) differential subsidence across the vast Chinle basin; and (2) differential erosion during development of the Tr-5 unconformity. Given the size of the basin, we suspect that differential subsidence is the more likely explanation.

7. Low in the Revueltian mudstone-dominated interval, persistent bed-level sandstone units correlative to the Saladito Point Bed include the Flattops 2, Painted Desert 3 and Chambers, Taaiylone, Chambers and Zuni River sandstones as well as the Perea Bed, all of east-central Arizona and west-central New Mexico. They probably represent a regional lowering of base-level during the early Revueltian, that lead to incision, followed by rising base level that lead to aggradation of high-sinuosity stream deposits.

8. Cyclically bedded strata (Rock Point and Redonda formations) are preserved at some localities but have been removed by post-Chinle erosion elsewhere. These youngest Chinle sediments yield Apachean-age fossils, including the type Apachean fauna from the Redonda Formation in Apache Canyon in east-central New Mexico.

Old ideas die hard, and one of the oldest incorrect ideas about Triassic deposition in the American Southwest is that two discrete depocenters existed, one in the Colorado Plateau region, the other in and around West Texas. To some extent this idea was an outgrowth of early, necessarily parochial stratigraphic studies, in which workers were confined to one or the other area by the logistical difficulties inherent to travel in the nineteenth and earlier part of the twentieth century. Notably, when earlier workers did cross from one study area to the other, some of the correlations advocated here were advanced (e.g., Case, 1928).

Unfortunately, the limited nature of earlier workers' studies was elaborated and perpetuated by parochial studies of local sedimentation patterns and an inability or unwillingness to recognize the lithologic similarity and continuity of Triassic strata from the Colorado Plateau to West Texas (e.g., McKee et al., 1959; Finch and Wright, 1983; McGowan et al., 1983; Johns and Granata, 1987; Dubiel, 1989; Lehman, 1994). Detailed lithostratigraphic and biostratigraphic studies demonstrate the interregional correlations (Lucas, 1993; Lucas et al., 1994), and recent sedimentological studies do not support the existence of a separate "Dockum basin" on the Southern High Plains (e.g., Riggs et al., 1996). The Triassic strata of the American Southwest are part of a single, vast depositional system, a Chinle basin, that extended from West Texas across New Mexico to Arizona, and northward into Nevada, Utah, Colorado and Wyoming.

ACKNOWLEDGMENTS

Numerous colleagues have worked with us on Triassic stratigraphic problems in east-central New Mexico. We thank all of them, especially O.J. Anderson and P. Huber. Numerous volunteers of the NMMNH, especially P. Bircheff, the Cotton family, N.V. "Dan" D'Andrea, R. Mongold, P. Sealey and the New Mexico Friends of Paleontology helped find and collect many of the fossils that made the biostratigraphy and biochronology advocated here possible. Orin Anderson and John Lorenz provided helpful reviews of the manuscript.

REFERENCES

Adams, J. E., 1929, Triassic of West Texas: American Association of Petroleum Geologists Bulletin, v. 12, p. 1045-1055.

Adkins, W. S., 1932, The Mesozoic systems in Texas: University of Texas. Bulletin 3232, p. 239-518.

Ash, S. R., 1972, Upper Triassic Dockum flora of eastern New Mexico and Texas: New Mexico Geological Society 23rd Field Conference, Guidebook, p. 124-128.

Ash, S. R., 1976, Occurrence of the controversial plant fossil *Sanmiguelia* in the Upper Triassic of Texas: Journal of Paleontology, v. 50, p. 799-804.

Ash, S. R., 1980, Upper Triassic floral zones of North America, *in* Dilcher, D. L., and Taylor, T. M., eds., Biostratigraphy of fossil plants: Stroudsburg, PA, Dowden, Hutchinson and Ross, p. 153-270.

Ash, S. R., 1988, Fossil plants from the mudstone member of the Santa Rosa Formation at the principal reference section: U.S. Geological Survey, Bulletin 1804C, p. 19-25.

Ash, S.R., 1989, A catalog of Upper Triassic plant megafossils of the western United States through 1988, *in* Lucas, S. G., and Hunt, A. P., eds., Dawn of the Age of Dinosaurs in the American Southwest: Albuquerque, New Mexico Museum of Natural History, p. 189-222.

Ash, S. R., and Morales, M., 1993, Anisian plants from Arizona: the oldest Mesozoic megaflora in North America: New Mexico Museum of Natural History and Science, Bulletin 3, p. 27-29.

Ballew, K. L., 1989, A phylogenetic analysis of Phytosauria from the Late Triassic of the western United States, *in* Lucas, S. G., and Hunt, A. P., eds., Dawn of the Age of Dinosaurs in the American Southwest: Albuquerque, New Mexico Museum of Natural History, p. 309-339.

Billingsley, G.H., 1985a, Geologic map of Petrified Forest National Park, Arizona: Unpublished Report to Petrified Forest Museum Association, Petrified Forest National Park, Arizona, 1 sheet.

Billingsley, G.H., 1985b, General stratigraphy of the Petrified Forest National Park, Arizona: Museum of Northern Arizona, Bulletin 54, p. 3-8.

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.

Boy, J. A., Schoch, R. R., and Lucas, S. G., 2001, The Moenkopi Formation in east-central New Mexico: Stratigraphy and vertebrate fauna: New Mexico Geological Society, 52nd Field Conference, Guidebook.

Broadhead, R. F., 1984, Subsurface petroleum geology of Santa Rosa Sandstone (Triassic), northeast New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 193, 22 p.

Broadhead, R. F., 1985, Stratigraphy and petroleum geology of Dockum Group (Triassic), northeastern New Mexico: New Mexico Geological Society, 36th Field Conference, Guidebook, p. 307-314.

Carpenter, K., 1997, A giant coelophysoid (Ceratosauria) theropod from the Upper Triassic of New Mexico, U.S.A.: Neues Jahrbuch für Geologie und Paläontologie Abhandlungen, v. 205, p. 189-206.

Carpenter, K., and Parrish, J.M., 1985, Late Triassic vertebrates from Revuelto Creek, Quay County, New Mexico: New Mexico Geological Society, 36th Field Conference, Guidebook, p. 197-198.

Case, E. C., 1914, The red beds between Wichita Falls, Texas and Las Vegas, New Mexico in relation to their vertebrate fauna: Journal of Geology, v. 22, p.

243-259.

Case, E. C., 1928, Indications of a cotylosaur and of a new form of fish from the Triassic beds of Texas, with remarks on the Shinarump Conglomerate: University of Michigan, Contributions of the Museum of Paleontology, v. 3, no. 1, p. 1-14.

Chatterjee, S., 1986, The Late Triassic Dockum vertebrates: Their stratigraphic and paleobiogeographic significance, *in* Padian, K., ed., The beginning of the age of dinosaurs: Faunal change across the Triassic-Jurassic boundary: Cambridge, Cambridge University Press, p. 139-150.

Colbert, E. H., and Imbrie, J., 1956, Triassic metoposaurid amphibians: Bulletin of the American Museum of Natural History, v. 110, p. 403-452.

Cooley, M. E., 1957, Geology of the Chinle Formation in the upper Little Colorado drainage area, Arizona and New Mexico [M.S. thesis]: Tucson, University of Arizona, 317 p.

Cornet, B., 1993, Applications and limitations of palynology in age, climatic, and paleoenvironmental analyses of Triassic sequences in North America: New Mexico Museum of Natural History and Science, Bulletin 3, p. 75-93.

Cotton, W. D., Cotton, J. E., and Hunt, A. P., 1997, Social behavior of Cretaceous ornithopod dinosaurs of New Mexico: New Mexico Museum of Natural History and Science, Bulletin 11, p. 45-50.

Cotton, W. D., Cotton, J. E., and Hunt, A. P., 1998, Evidence for social behavior in ornithopod dinosaurs from the Dakota Group of northeastern New Mexico, U.S.A.: Ichnos, v. 6, p. 141-149.

Dane, C. H., and Bachman, G. O., 1965, Geologic map of New Mexico: Washington, D. C., U. S. Geological Survey, 2 sheets, scale 1:500,000.

Darton, N. H., 1922, Geologic structure of parts of New Mexico: U.S. Geological Survey, Bulletin 726-E, p. 275.

Darton , N. H., 1928, "Red beds" and associated formations in New Mexico, with an outline of the geology of the state: U. S. Geological Survey, Bulletin 794, 372 p.

Dobrovolny, E., Bates, R. L., and Summerson, C. H., 1946, Geology of northwestern Quay County, New Mexico: U. S. Geological Survey, Oil and Gas Investigations Map OM-62, 2 sheets.

Dubiel, R. F., 1989, Depositional and climatic setting of the Upper Triassic Chinle Formation, Colorado Plateau, *in* Lucas, S. G., and Hunt, A. P., eds., Dawn of the Age of Dinosaurs in the American Southwest: Albuquerque, New Mexico Museum of Natural History, p. 171-187.

Dunay, R. E., and Fisher, M. J., 1974, Late Triassic palynofloras of North America and their European correlatives: Review of Palaeobotany and Palynology, v. 17, p. 179-186.

Dunay, R. E., and Fisher, M J., 1979, Palynology of the Dockum Group (Upper Triassic), Texas, U.S.A.: Review of Palaeobotany and Palynology, v. 28, p. 61-92.

Espegren, W. A., 1985, Sedimentology and petrology of the upper Petrified Forest Member of the Chinle Formation, Petrified Forest National Park and vicinity, Arizona [M.S. Thesis]: Flagstaff, Northern Arizona University, 229 p.

Finch, W. I., and Wright, J. C., 1983, Measured stratigraphic sections of uranium-bearing Upper Triassic rocks in eastern New Mexico, west Texas, and the Oklahoma Panhandle with brief discussion of stratigraphic problems: U.S. Geological Survey, Open-file Report 83-701, 118 p.

Finch, W. I., Wright, J. C., and Davis, B. O., 1976, Unevaluated preliminary geologic cross section of uranium-bearing Upper Triassic rocks extending from Ute Reservoir, New Mexico, to Palo Duro Canyon, Texas U.S. Geological Survey, Open-file Report 76-205, 1 sheet.

Fritz, T., 1991, Depositional history of the mid-Late Triassic Santa Rosa Formation, eastern New Mexico [M.S. thesis]: Lubbock, Texas Tech University, 120 p.

Goddard, E. N., Trask, P. D., DeFord, R. K., Rove, O. N., Singewald, G. T. J., and Overbeck, R. M., 1984, Rock Color Chart: Boulder, Geological Society of America.

Good, S. C., 1989, Nonmarine Mollusca in the Upper Triassic Chinle Formation and related strata of the Western Interior, *in* Lucas, S. G., and Hunt, A. P., eds., Dawn of the Age of Dinosaurs in the American Southwest: Albuquerque, New Mexico Museum of Natural History, p. 233-248.

Good, S. C., 1993a, Molluscan paleobiology of the Upper Triassic Chinle Formation, Arizona and Utah [Ph.D. thesis]: Boulder, University of Colorado, 270 p.

Good, S. C., 1993b, Stratigraphic distribution of the mollusc fauna of the Chinle Formation and molluscan biostratigraphic zonation: New Mexico Museum of Natural History and Science, Bulletin 3, p. 155-159.

Good, S.C., 1998, Freshwater bivalve fauna of the Late Triassic (Carnian-Norian) Chinle, Dockum and Dolores formations of the southwest United States, *in* Johnston, P.O. and Haggart, J.W., eds., Bivalves: An Eon of Evolution—Paleobiological Studies Honoring Norman D. Newell: Calgary, University of Calgary Press, p. 223-249.

Gorman, J. M., and Robeck, R. C., 1946, Geology and asphalt deposits of north-central Guadalupe County, New Mexico: U. S. Geological Survey, Oil and Gas Investigations Preliminary Map OM-44.

Gould, C. N., 1907, The geology and water resources of the western portion of the Panhandle of Texas: U.S. Geological Survey, Water-supply Paper 191, 170 p.

Granata, G. E., 1981, Regional sedimentation of the Late Triassic Dockum Group, west Texas and eastern New Mexico [M.A. thesis]: Austin, University of Texas, 199 p.

Gregory, J. T., 1972, Vertebrate faunas of the Dockum Group, Triassic, eastern New Mexico and west Texas: New Mexico Geological Society, 23rd Field Conference, Guidebook, p. 120-123.

Griggs, R. L., and Hendrickson, G. E., 1951, Geology and ground-water resources of San Miguel County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Ground-water Report 2, 121 p.

Griggs, R. L., and Read, C. B., 1959, Revisions in stratigraphic nomenclature in Tucumcari-Sabinoso area, northeastern New Mexico: American Association of Petroleum Geologists Bulletin, v. 43, p. 2003-2007.

Heckert, A. B., and Lucas, S. G., 1996, Stratigraphic description of the Tr-4 unconformity, west-central New Mexico and eastern Arizona: New Mexico Geology, v. 18, no. 3, p. 61-70.

Heckert, A. B., and Lucas, S. G., 1998, First occurrence of *Aetosaurus* (Reptilia:Archosauria) in the Upper Triassic Chinle Group (USA) and its biochronological significance: Neues Jahrbuch für Geologie und Paläontologie Monatshefte, v. 1998, p. 604-612.

Heckert, A. B., Hunt, A. P., and Lucas, S. G., 1996, Redescription of *Redondasuchus reseri*, a Late Triassic aetosaur (Reptilia:Archosauria) from New Mexico (U.S.A) and the biochronology and phylogeny of aetosaurs: Geobios, v. 29, p. 619-632.

Heckert, A. B., Lucas, S. G., and Sullivan, R. M., 2000, Triassic dinosaurs in New Mexico: New Mexico Museum of Natural History and Science, Bulletin17, p. 17-26.

Heckert, A.B., Lucas, S.G., Hunt, A.P., and Harris, J.D., 2001, A giant phytosaur (Reptilia: Archosauria) skull from the Redonda Formation (Upper Triassic: Apachean) of east-central New Mexico: New Mexico Geological Society, 52nd Field Conference Guidebook.

Hester, P. M., 1988, Depositional environments of a Late Triassic lake, east-central New Mexico [M.S. thesis]: Albuquerque, University of New Mexico, 152 p.

Hester, P. M., and Lucas, S. G., 2001, Depositional environments of a Late Triassic lake, east-central New Mexico New Mexico: Geological Society, 52nd Field Conference Guidebook.

Huber, P., Lucas, S. G., and Hunt, A. P., 1993, Late Triassic fish assemblages of the North American Western Interior: Museum of Northern Arizona, Bulletin 59, p. 51-66.

Hunt, A. P., 1989a, Comments on the taxonomy of North American metoposaurs and a preliminary phylogenetic analysis of the family Metoposauridae, *in* Lucas, S. G., and Hunt, A. P., eds., Dawn of the Age of Dinosaurs in the American Southwest: Albuquerque, New Mexico Museum of Natural History, p. 293-300.

Hunt, A. P., 1989b, Cranial morphology and ecology among phytosaurs, *in* Lucas, S. G., and Hunt, A. P., eds., Dawn of the Age of Dinosaurs in the American Southwest: Albuquerque, New Mexico Museum of Natural History, p. 349-354.

Hunt, A. P., 1989c, A new ?ornithischian dinosaur from the Bull Canyon Formation (Upper Triassic) of east-central New Mexico, *in* Lucas, S. G., and Hunt, A. P., eds., Dawn of the age of dinosaurs in the American Southwest: Albuquerque, New Mexico Museum of Natural History, p. 355-358.

Hunt, A. P., 1991, The first tetrapod faunas from the Trujillo Formation (Late Triassic) of east-central New Mexico and their biochronological and paleoecological significance: New Mexico Geology, v. 13, p. 93.

Hunt, A. P., 1993, Revision of the Metoposauridae (Amphibia: Temnospondyli) and description of a new genus from western North America: Museum of

Northern Arizona, Bulletin 59, p. 67-97.

Hunt, A P., 1994, Vertebrate paleontology and biostratigraphy of the Bull Canyon Formation (Chinle Group: Norian), east-central New Mexico with revisions of the families Metoposauridae (Amphibia: Temnospondyli) and Parasuchidae (Reptilia: Archosauria) [Ph.D. dissertation]: Albuquerque, University of New Mexico, 403 p.

Hunt, A. P., 1997a, E.C. Case, J.T. Gregory and early explorations for fossil vertebrates in the Bull Canyon Formation (Upper Triassic) of eastern New Mexico: New Mexico Museum of Natural History and Science Bulletin 11, p. 15-24.

Hunt, A. P., 1997b, A new coelacanth (Osteichthyes: Actinistia) from the continental Upper Triassic of New Mexico: New Mexico Museum of Natural History and Science, Bulletin 11, p. 25-28.

Hunt, A.P., 2001a, Paleontology and age of the Upper Triassic Trujillo Formation, east-central New Mexico and west Texas: New Mexico Geological Society, 52nd Field Conference Guidebook.

Hunt, A. P., 2001b, The vertebrate fauna, biostratigraphy and biochronology of the type Revueltian land-vertebrate faunachron, Bull Canyon Formation (Upper Triassic), east-central New Mexico: New Mexico Geological Society, 52nd Field Conference Guidebook.

Hunt, A. P., and Lucas, S. G., 1989, Late Triassic vertebrate localities in New Mexico, *in* Lucas, S. G., and Hunt, A. P., eds., Dawn of the Age of Dinosaurs in the American Southwest: Albuquerque, New Mexico Museum of Natural History, p. 72-101.

Hunt, A. P., and Lucas, S. G., 1991a, A new aetosaur from the Upper Triassic of eastern New Mexico: Neues Jahrbuch für Geologie und Paläontologie Monatshefte, v. 1991, p. 728-736.

Hunt, A. P., and Lucas, S. G., 1991b, The *Paleorhinus* biochron and the correlation of the nonmarine Upper Triassic of Pangaea: Palaeontology, v. 34, p. 487-501

Hunt, A. P., and Lucas, S. G., 1993a, Triassic vertebrate paleontology and biochronology of New Mexico: New Mexico Museum of Natural History and Science, Bulletin 2, p. 49-60.

Hunt, A. P., and Lucas, S. G., 1993b, Late Triassic microvertebrate localities in New Mexico (USA): Implications for paleoecology: New Mexico Museum of Natural History and Science, Bulletin 3, p. 187-191.

Hunt, A. P., and Lucas, S. G., 1993c, A new phytosaur (Reptilia: Archosauria) genus from the uppermost Triassic of the western United States and its biochronological significance: New Mexico Museum of Natural History and Science, Bulletin 3, p. 193-196.

Hunt, A. P., and Lucas, S. G., 1994, Ornithischian dinosaurs from the Upper Triassic of the United States; *in* Fraser, N. C., and Sues, H.-D., eds., In the shadow of the dinosaurs: Early Mesozoic tetrapods: Cambridge, Cambridge University Press, p. 227-241.

Hunt, A. P., and Lucas, S. G., 1995, Vertebrate paleontology and biochronology of the Lower Chinle Group (Upper Triassic), Santa Fe County, north-central New Mexico: New Mexico Geological Society, 46th Field Conference, Guidebook, p. 243-246.

Hunt, A. P., and Lucas, S. G., 1997, Stratigraphy, paleontology and biochronology of the Upper Triassic Chinle Group in east-central New Mexico: Southwest Paleontological Symposium Proceedings, v. 1, p. 25-40.

Hunt, A. P., and Lucas, S. G., 2001, The first vertebrate track (*Brachychirotherium*) from the upper Carnian Garita Creek Formation, east-central New Mexico: New Mexico Geological Society, 52nd Field Conference, Guidebook.

Hunt, A. P., Lockley, M. G., and Lucas, S. G., 1993a, Vertebrate and invertebrate tracks and trackways from Upper Triassic strata of the Tucumcari basin, east-central New Mexico: New Mexico Museum of Natural History and Science, Bulletin 3, p. 199-201.

Hunt, A. P., Lucas, S. G., and Kietzke, K. K., 1989a, Dinosaur footprints from the Redonda Member of the Chinle Formation (Upper Triassic), east-central New Mexico; *in* Gillette, D. D. and Lockley, M. G., eds., Dinosaur tracks and traces: Cambridge, Cambridge University Press, p. 277-280.

Hunt, A. P., Lucas, S. G., and Reser, P. K., 1993b, A complete skeleton of the stagonolepidid *Typothorax coccinarum* from the Upper Triassic Bull Canyon Formation of east-central New Mexico, U.S.A.: New Mexico Museum of Natural History and Science, Bulletin 3, p. 209-212.

Hunt, A. P., Lucas, S. G., and Sealey, P. L., 1989b, Paleontology and vertebrate biochronology of the Upper Triassic Garita Creek Formation, east-central New Mexico: New Mexico Journal of Science, v. 29, p. 61-68.

Hunt, A. P., Lucas, S. G., Lockley, M. G. and Heckert, A. B., 2000, Occurrence of the dinosaurian ichnogenus *Grallator* in the Redonda Formation (Upper Triassic: Norian) of eastern New Mexico: New Mexico Museum of Natural History and Science Bulletin 17, p. 39-41.

Hunt, A. P., Lucas, S. G., Heckert, A. B., Sullivan, R. M., and Lockley, M. G., 1998, Late Triassic dinosaurs from the western United States: Geobios, v. 31, p. 511-531.

Johns, D. A., and Granata, G. E., 1987, Regional tectonic setting and depositional trends of the Dockum Group, West Texas and eastern New Mexico: Journal of the Arizona-Nevada Academy of Science, v. 22, p. 53-72.

Kelley, V. C., 1972a, Triassic rocks of the Santa Rosa area: New Mexico Geological Society, 23rd Field Conference, Guidebook, p. 84-90.

Kelley, V. C., 1972b, Geology of the Fort Sumner sheet, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 98, 55 p.

Kietzke, K.K., 1987, Calcareous microfossils from the Upper Triassic of northeastern New Mexico: New Mexico Geological Society, 38th Fall Field Conference Guidebook, p. 119-126.

Kietzke, K. K., 1989, Calcareous microfossils from the Triassic of the southwestern United States, *in* Lucas, S. G., and Hunt, A. P., eds., Dawn of the Age of Dinosaurs in the American Southwest: Albuquerque, New Mexico Museum of Natural History, p. 223-232.

Kues, B.S., 1985, Nonmarine molluscs from the Chinle Formation, Dockum Group (Upper Triassic), of Bull Canyon, Guadalupe County, New Mexico: New Mexico Geological Society, 36th Field Conference, Guidebook, p. 185-196

Lehman, T. M., 1994, The saga of the Dockum Group and the case of the Texas/New Mexico boundary fault: New Mexico Bureau of Mines and Mineral Resources, Bulletin 150, p. 37-52.

Lehman, T., Chatterjee, S., and Schnable, J., 1992, The Cooper Canyon Formation (Late Triassic) of western Texas: Texas Journal of Science, v. 44, p. 349-355.

Litwin, R. J., Traverse, A., and Ash, S. R., 1991, Preliminary palynological zonation of the Chinle Formation, southwestern U.S.A., and its correlation to the Newark Supergroup: Review of Palaeobotany and Palynology, v. 68, p. 269-287.

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.

Lockley, M. G., and Hunt, A. P., 1999, Dinosaur Tracks and Other Fossil Footprints of the Western United States. New York, Columbia University Press (revised paperback edition), 338 p.

Lockley, M. G., Lucas, S. G., and Hunt, A. P., 2000, Dinosaur tracksites in New Mexico: A review: New Mexico Museum of Natural History and Science, Bulletin 17, p. 9-16.

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, p. 254 p.

Lucas, S. G., 1991, Correlation of Triassic strata of the Colorado Plateau and southern High Plains, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 137, p. 47-56.

Lucas, S. G., 1993, The Chinle Group: Revised stratigraphy and biochronology of Upper Triassic nonmarine strata in the western United States: Museum of Northern Arizona, Bulletin 59, p. 27-50.

Lucas, S. G., 1995, Triassic stratigraphy and chronology in New Mexico: New Mexico Geology, v. 17, p. 8-13, 17.

Lucas, S. G., 1997, The Upper Triassic Chinle Group, western United States, nonmarine standard for Late Triassic time, *in* Dickins, J. M., Yang, Z., Yin, H., Lucas, S. G., and Acharyya, S. K., eds., Permo-Triassic of the circum-Pacific: Cambridge, Cambridge University Press, p. 200-228.

Lucas, S. G., 1998, Global Triassic tetrapod biostratigraphy and biochronology: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 143, p. 347-384.

Lucas, S. G., 2000, Tetrapod-based correlation of the nonmarine Triassic: Zentralblatt für Geologie und Paläontologie, v. 2000, no. 7-8, p. 497-521.

Lucas, S.G., 2001, The bennettitalean *"Zamites" powellii* from the Middle Triassic Moenkopi Formation, east-central New Mexico: New Mexico Geological Society, 52nd Field Conference Guidebook.

Lucas, S. G., and Anderson, O. J., 1992, Triassic stratigraphy and correlation, west Texas and eastern New Mexico, *in* Cromwell, D. W., Moussa, M. T., and Mazzullo, L. J., eds., Transactions Southwest Section AAPG, Midland, Texas, 1992: Midland, West Texas Geological Society, p. 201-207.

Lucas, S. G., and Anderson, O. J., 1993, Triassic stratigraphy in southeastern New

Mexico and southwestern Texas: New Mexico Geological Society, 44th Field Conference, Guidebook, p. 231-235.

Lucas, S. G., and Hayden, S. N., 1989, Triassic stratigraphy of west-central New Mexico: New Mexico Geological Society 40th Field Conference Guidebook, p. 191-211.

Lucas, S. G., and Hayden, S. N., 1991,Type section of the Permian Bernal Formation and the Permian-Triassic boundary in north-central New Mexico: New Mexico Geology, v. 13, p. 9–15.

Lucas, S. G., and Heckert, A. B., 1994, Triassic stratigraphy in the Lucero uplift, Cibola, Valencia and Socorro counties, New Mexico: New Mexico Geological Society 45th Field Conference, Guidebook, p. 241-254.

Lucas, S. G., and Hunt, A. P., 1987, Stratigraphy of the Anton Chico and Santa Rosa Formations, Triassic of east-central New Mexico: Journal of the Arizona-Nevada Academy of Science, v. 22, p. 21-33.

Lucas, S. G., and Hunt, A. P., 1989, Revised Triassic stratigraphy, Tucumcari basin, east-central New Mexico; *in* Lucas, S. G., and Hunt, A. P., eds., Dawn of the Age of Dinosaurs in the American Southwest: Albuquerque, New Mexico Museum of Natural History, p. 150-170.

Lucas, S. G., and Hunt, A. P., 1993, Tetrapod biochronology of the Chinle Group (Upper Triassic), western United States: New Mexico Museum of Natural History and Science, Bulletin 3, p. 327-329.

Lucas, S.G., and Morales, M., 1985, Middle Triassic amphibian from basal Santa Rosa Formation, east-central New Mexico: New Mexico Geological Society, 36th Field Conference, Guidebook, p. 56-58.

Lucas, S. G., and Oakes, W., 1988, A Late Triassic cynodont from the American South-West: Palaeontology, v. 31, p. 445-449.

Lucas, S. G., Anderson, O. J., and Hunt, A. P., 1994, Triassic stratigraphy and correlations, southern High Plains of New Mexico-Texas: New Mexico Bureau of Mines and Mineral Resources, Bulletin 150, p. 105-126.

Lucas, S. G., Estep, J. W., and Hunt, A. P., 1998, Giant erythrosuchid archosaur from the Middle Triassic Moenkopi Formation, east-central New Mexico: Geological Society of America Abstracts with Programs, v. 30, no. 6, p. 13-14.

Lucas, S. G., Heckert, A. B., and Anderson, O. J., 1997, Triassic stratigraphy and paleontology on the Fort Wingate quadrangle, west-central New Mexico: New Mexico Geology, v. 19, p. 33-42.

Lucas, S. G., Heckert, A. B., and Estep, J. W., 1999a, Correlation of Triassic strata across the Rio Grande rift, north-central New Mexico: New Mexico Geological Society, 50th Field Conference, Guidebook, p. 305-310.

Lucas, S.G., Hunt, A.P., and Huber, P., 1990, Triassic stratigraphy in the Sangre de Cristo Mountains, New Mexico: New Mexico Geological Society, 41st Field Conference, Guidebook, p. 305-318.

Lucas, S. G., Hunt, A. P., and Bennett, S. C., 1985b, Triassic vertebrates from east-central New Mexico in the Yale Peabody Museum: New Mexico Geological Society, 36th Field Conference, Guidebook, p. 199-203.

Lucas, S. G., Hunt, A. P., and Kietzke, K. K., 1985d, *Neocalamites* forest in the Upper Triassic of Bull Canyon, New Mexico: New Mexico Geological Society, 36th Field Conference, Guidebook, p. 8-9.

Lucas, S. G., Hunt, A. P. and Lockley, M. G., 2001a, Tetrapod footprint ichnofauna of the Upper Triassic Redonda Formation, Chinle Group, Quay County, New Mexico: New Mexico Geological Society, 52nd Field Conference, Guidebook.

Lucas, S. G., Hunt, A. P., and Morales, M., 1985a, Stratigraphic nomenclature and correlation of Triassic rocks of east-central New Mexico: A preliminary report: New Mexico Geological Society, 36th Field Conference, Guidebook, p. 171-184.

Lucas, S. G., Oakes, W., and Froehlich, J. W., 1985c, Triassic microvertebrate locality, Chinle Formation, east-central New Mexico: New Mexico Geological Society, 36th Field Conference, Guidebook, p. 205-212.

Lucas, S. G., Estep, J. W., Heckert, A. B., and Hunt, A. P., 1999b, Cynodont teeth from the Upper Triassic of New Mexico, U.S.A.: Neues Jahrbuch für Geologie und Paläontologie Monatsheft, v. 1999, p. 331-344.

Lucas, S. G., Hunt, A. P., Heckert, A. B., Kues, B. S., and McLemore, V. T., 2001b, Third-day road log, from Tucumcari to Conchas Dam, New Mexico: New Mexico Geological Society, 52nd Field Conference Guidebook.

Marcou, J., 1858, Geology of North America, With Reports on the Prairies of Arkansas and Texas, the Rocky Mountains of New Mexico, and the Sierra Nevada of California, Originally Made for the United States Government: Zurich, Zurcher and Furrer, 144 p.

Matthes, G. H., 1936, Problems at Conchas Dam: Civil Engineering, v. 6, p. 437-441.

McGowan, J. H., Granata, G. E., and Seni, S. J., 1983, Depositional setting of the Triassic Dockum Group, Texas Panhandle and eastern New Mexico, *in* Reynolds, M. W., and Dolly, E. D., eds., Mesozoic Paleogeography of the West-central United States: Denver, Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, p. 13-38.

McKee, E.D., Oriel, S.S., Ketner, K.B., MacLachlan, M.E.H., Goldsmith,J.W., MacLachlan, J.C., and Mudge, M.R., 1959, Paleotectonic maps of the Triassic System: U.S. Geological Survey, Miscellaneous Geological Investigations Map I-300, 33 p.

Murry, P. A., 1986, Vertebrate paleontology of the Dockum Group, western Texas and eastern New Mexico, *in* Padian, K., ed., The beginning of the age of dinosaurs: Faunal change across the Triassic-Jurassic boundary: Cambridge, Cambridge University Press, p. 109-137.

Murry, P. A., 1989, Geology and paleontology of the Dockum Formation (Upper Triassic), West Texas and eastern New Mexico, *in* Lucas, S. G., and Hunt, A. P., eds., Dawn of the Age of Dinosaurs in the American Southwest: Albuquerque, New Mexico Museum of Natural History, p. 102-148.

Newell, A. J., 1993, Depositional environment of the Late Triassic Bull Canyon Formation (New Mexico): implications for "Dockum Formation" paleogeography: New Mexico Museum of Natural History and Science, Bulletin 3, p. 359-368.

Parrish, J. M., 1989, Late Triassic tetrapods of the North American Southwest, *in* Lucas, S. G., and Hunt, A. P., eds., Dawn of the Age of Dinosaurs in the American Southwest: Albuquerque, New Mexico Museum of Natural History, p. 360-374.

Parrish, J. M., and Carpenter, K., 1986, A new vertebrate fauna from the Dockum Formation (Late Triassic) of eastern New Mexico, *in* Padian, K., ed., The beginning of the age of dinosaurs: Faunal change across the Triassic-Jurassic boundary: Cambridge, Cambridge University Press, p. 151-160.

Pipiringos, G. N., and O'Sullivan, G. S., 1978, Principal unconformities in Triassic and Jurassic rocks, western interior United States—a preliminary survey: U.S. Geological Survey, Professional Paper 1035-A, p. 1-29.

Reeside, J. B., Jr., Applin, P. L., Colbert, E. H., Hadley, H. D., Kummel, B., Lewis, P. J., Love, J. D., Maldanado-Koerdell, M., McKee, E. D., McLaughlin, D. B., Muller, S. W., Rodgers, J., Sanders, J., Silberling, N. J., and Waage, K., 1957, Correlation of the Triassic formations of North America exclusive of Canada: Geological Society of America Bulletin, v. 68, p. 1451-1514.

Rich, J. L., 1921, The stratigraphy of eastern New Mexico—a correction: American Journal of Science, series 5, v. 2, p. 295-298.

Riggs, N. R., Lehman, T. M., Gehrets, G. E., and Dickinson, W. R., 1996, Detrital zircon link between headwaters and terminus of the Upper Triassic Chinle-Dockum paleo-river system: Science, v. 273, p. 97-100.

Romer, A. S., 1939, An amphibian graveyard: Scientific Monthly, v. 49, p. 337-339.

Spiegel, Z., 1972, Cenozoic geology of the Canadian River valley, New Mexico: New Mexico Geological Society 23rd Field Conference, Guidebook, p. 118-119.

Stewart, J. H., Poole, F. G., and Wilson, R. 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, 336 p.

Trauger, F. D., Mankin, C. J., and Brand, J. P., 1972, Road log of Tucumcari, Mosquero, and San Jon country: New Mexico Geological Society, 23rd Field Conference, Guidebook, p. 12-45.

Wanek, A. A., 1962, Reconnaissance geologic map of parts of Harding, San Miguel, and Mora counties, New Mexico: Washington, U. S. Geological Survey Oil and Gas Investigations Map OM 209, 1 sheet.

APPENDIX—DESCRIPTION OF MEASURED SECTIONS

PUERTO DE LUNA

Measured just east of NM Highway 31 between Santa Rosa and Puerto de Luna. Section base at UTM 53138E, 3863675N (zone 13, NAD 27) and top at 531480E, 3863734N. Strata are flat-lying.

unit lithology **thickness (m)**

Chinle Group: Santa Rosa Formation: Tecolotito Member:

15 Sandstone; very pale orange (10YR8/2) and pale yellowish brown (10YR6/2); very fine-to fine-grained; quartzarenite; calcareous; trough crossbedded. **not measured**

14 Conglomerate; moderate yellowish brown (10YR5/4) and pale yellowish brown (10YR6/2); clasts are up to 1.5 cm in diameter and are mostly limestone; matrix is a fine- to coarse-grained litharenite; massive. **1.3**

unconformity (Tr-3 unconformity of Pipiringos and O'Sullivan, 1978):

Moenkopi Formation: Anton Chico Member:

13 Sandstone; speckled very pale orange (10YR8/2) and pale yellowish brown (10YR6/2); fine-grained; hematitic quartzarenite; laminar with some low angle trough crossbeds. **1.4**

12 Sandy siltstone; grayish red (10R4/2); not calcareous; laminar (flaggy); forms a slope. **2.9**

11 Sandstone; same color and lithology as unit 7. **0.6**

10 Sandstone; same color and lithology as unit 9; scour base; paleoflow (based on crossbed dips) to N20°W. **2.3**

9 Sandstone; grayish red (10R4/2) to pale red (10R6/2); fine-grained; slightly micaceous litharenite; very calcareous; trough crossbedded. **1.6**

8 Sandstone; same color and lithology as unit 9 but with mud-chip conglomerate locally at base. **2.1**

7 Sandstone; same color and lithology as unit 9. **1.3**

6 Sandstone; pale red (10R6/2) and yellowish gray (5Y8/10; fine- to medium-grained; micaceous litharenite; very calcareous; trough crossbedded; lenses of mud-pellet conglomerate in lower 0.5 m; paleocurrent azimuths to N50°W. **1.8**

5 Conglomeratic sandstone; pale reddish brown (10R5/4); fine- to medium-grained; micaceous litharenite; very calcareous; mud pebbles up to 7 mm in diameter; trough crossbedded. **0.7**

4 Sandstone; grayish red (10R4/2); very fine-grained; micaceous litharenite; trough crossbedded. **2.0**

3 Sandstone; pale red (10R6/2); very fine-grained; micaceous litharenite; calcareous; trough crossbedded. **1.5**

2 Sandstone; very pale orange (10YR8/2) to yellowish gray (5Y8/1); fine-grained; micaceous litharenite; calcareous; trough crossbedded. **1.4**

unconformity (Tr-2 and older unconformities of Pipiringos and O'Sullivan, 1978)

Artesia Group:

1 Sandy siltstone; pale reddish brown (10R5/4); not calcareous; ripple laminated. **not measured**

CONCHAS DAM

Measured on the north side of the Canadian River near the first bend east of Conchas Dam. Section base at UTM 574796E, 3918639N (zone 13, NAD 27) and top at 574248E, 3918392N. Strata are flat-lying.

unit lithology **thickness (m)**

Chinle Group: Garita Creek Formation:

19 Sandy mudstone; same color and lithology as unit 17. **not measured**

18 Sandstone; grayish red (10R4/2); very fine-grained; litharenite; calcareous; ripple laminated bench; *Brachychirotherium* tracks. **0.4**

17 Sandy mudstone; grayish red (10R4/2); very calcareous. **2.7**

Santa Rosa Formation: Tres Lagunas Member:

16 Sandstone; same color and lithology as unit 14. **0.8**

15 Sandstone; grayish orange (10YR7/4); very fine grained; hematitic quartzarenite; calcareous; ripple laminated. **2.8**

14 Sandstone; grayish orange (10YR7/4); very fine-grained; hematitic quartzarenite; calcareous; trough crossbedded. **1.6**

13 Sandstone; pale yellowish brown (10YR6/2) and grayish orange (10YR7/4); very fine- to fine-grained; micaceous quartzarenite; platy to ripple laminated. **2.5**

12 Conglomerate; matrix supported; matrix is pale yellowish brown (10YR6/2); very fine to fine-grained; micaceous quartzarenite; clasts are light brownish gray (4YR6/1) limestone (calcrete) pebbles up to 5 cm in diameter; trough crossbedded; base of unit is a scour surface with as much as 1 m of relief locally. **2.3**

unconformity:

Los Esteros Member:

11 Silty sandstone; pale red (10R6/2) to pale yellowish brown (10YR6/2); very fine- to fine-grained; micaceous quartzarenite; calcareous; ripple laminated. **3.3**

10 Silty sandstone; pale reddish brown (10R5/4); very fine-grained; micaceous litharenite; calcareous; ripple laminated. **1.5**

9 Silty shale; grayish red (10R4/2); micaceous; not calcareous. **0.5**

8 Silty sandstone; pale reddish brown (10R5/4); very fine-grained; micaceous quartzarenite; ripple laminated with mudstone drapes. **0.9**

7 Sandstone; pale yellowish brown (10YR6/2) and grayish orange (10YR7/4); very fine-grained; micaceous quartzarenite; slightly calcareous; ripple laminated; forms a bench. **1.0**

6 Shale; grayish red (10R4/2) and yellowish gray (5Y7/2) mottling; not calcareous; some lenses of pebbly sandstone that are grayish orange (10YR7/4); fine-grained; clayey; micaceous litharenite. **5.5**

Tecolotito Member:

5 Sandstone; dark yellowish orange (10YR6/6) and pale yellowish brown (10YR6/2)fine to medium-grained; micaceous quartzarenite; calcareous; trough crossbedded; top ripple laminated. **6.1**

4 Sandstone; speckled very pale orange (10YR8/2) and pale yellowish brown (10YR6/2); fine- to medium-grained; quartzarenite; very calcareous; trough crossbedded. **3.5**

3 Conglomeratic sandstone; same colors as unit 4; medium to coarse grained; quartzarenite; calcareous. **1.3**

2 Conglomerate; pinkish gray (5YR8/1); matrix is fine- to coarse-grained quartzarenite; clasts are up to 15 cm in diameter and are extraformational lithics, fossiliferous Paleozoic limestones and quartzite. **2.0**

unconformity: (Tr-3 unconformity of Pipiringos and O'Sullivan, 1978)

Moenkopi Formation: Anton Chico Member:

1 Mudstone and siltstone; pale reddish brown (10R5/4); very calcareous; mostly covered. **5+**

SALADITO POINT

Measured just east of NM Highway 129 between Conchas Dam and Newkirk. Section base at UTM 566672E, 3885289N (zone 13, NAD 27) and top at 567o16E, 2885174N. Strata are flat-lying.

unit lithology **thickness (m)**

Chinle Group: Bull Canyon Formation:

17 Conglomeratic sandstone; grayish red (10R4/2); matrix is medium- to coarse-grained; clasts are limestone (calcrete); litharenite calcareous; trough crossbedded; paleocurrent azimuths (crossbed dips) are to 280°. **1.0**

16 Muddy sandstone; pale reddish brown (10R5/4); very fine-grained; litharenite; forms a slope. **3.3**

Saladito Point Bed (units 9-15 form type section)

15 Sandstone; pale reddish brown (10R5/4); very fine-grained; micaceous litharenite; calcareous; trough crossbedded. **4.0**

14 Sandstone; pale reddish brown (10R5/4); very fine-grained; micaceous litharenite; not calcareous; thinly laminated. **1.5**

13 Sandstone; pale reddish brown (10R5/4); fine-grained; micaceous litharenite; not calcareous; laminated. **1.1**

12 Sandstone; pale reddish brown (10R5/4); fine-grained; micaceous litharenite; trough crossbedded. **2.8**

11 Conglomeratic sandstone; grayish red (10R4/2); matrix is fine-grained micaceous litharenite; clasts are mudstone, siltstone and calcrete rip-ups up to 4 mm in diameter; calcareous; massive. **1.4**

10 Sandstone; pale reddish brown (10R5/4); very fine- to fine-grained; micaceous litharenite; calcareous; trough crossbedded. **1.1**

9 Conglomerate; same lithology as unit 11 but less matrix; trough crossbedded. **0.3**

Bull Canyon Formation:

8 Silty mudstone; pale reddish brown (10R5/4); calcareous; forms a long slope. **14.3**

7 Calcrete; nodular; pale reddish brown (10R5/4); nodules up to 4 cm diameter; coprolites. **0.7**

6 Silty mudstone; same color and lithology as unit 8. **2.5**

5 Sandstone; pale reddish brown (10R5/4) and light greenish gray (5GY8/1); very fine-grained; micaceous litharenite; very calcareous; thinly laminated and ripple laminated. **0.7**

4 Silty mudstone; same color and lithology as unit 8. **9.9**

3 Conglomerate; light brownish gray (5YR6/1); clasts are limestone and chert pebbles up to 1 cm in diameter; contains coprolites and bone fragments of metoposaurs and phytosaurs. **0.4**

2 Silty mudstone; pale red (10R6/2); calcareous. **1.4**

Trujillo Formation:

1 Sandstone; light olive gray (5Y6/1); fine-grained; subarkosic; not calcareous; trough crossbedded; floors the flats around base of the mesa. **Not measured**

BARRANCA CREEK, SECTION A

Section A was measured in the NE1/4 NE1/4 SW1/4 and NW1/4 NW1/4 SE1/4 Sec.

6 T11N, R33E, NW1/4 and SW1/4 SW1/4 SE1/4 Sec. 1, T10N, R32E and SE1/4 SE1/4 SW1/4 Sec. 1, T10N, 32E, Quay, County, New Mexico.

unit lithology **thickness (m)**

Chinle Group: Bull Canyon Formation:

16 Sandstone; moderate reddish brown (10R4/6); very fine grained; well sorted; rounded to subrounded; quartzose with mica, feldspar and lithic fragments; mildly calcareous; channelform with undulating erosional base; ripple laminar; trough and planar crossbeds. **6.0**

15 Sandstone and siltstone; sandstone is pale yellowish green (10GY7/2); very fine grained; well sorted; well rounded; quartzose; not calcareous; platy: siltstone is siltstone-silty mudstone; moderate reddish brown (10R4/6); very calcareous. **4.7**

14 Sandstone and siltstone-very fine sandstone; sandstone is pale green (5G7/2); very fine grained; moderately sorted; subrounded to subangular; quartzose; highly calcareous; siltstone-very fine sandstone is grayish red (10R4/2) and pale red purple (5RP6/2); poorly sorted; subrounded; quartzose; highly calcareous; several vertebrate localities including NMMNH localities 6 and 7. **3.0**

13 Conglomerate; light greenish gray (5G8/1); clasts are mainly limestone, few are siltstone (moderate reddish brown (10R4/6); well rounded up to 9 mm in diameter; matrix is sandstone; fine-coarse grained; poorly sorted; moderately rounded; quartzose with lithic fragments; highly calcareous; ledge-former, often forms top of small cliff. **0.5**

12 Conglomerate and sandstone; conglomerate as 13, but limestone clasts are light olive gray (5Y6/1); forms lower 0.4 m of unit; sandstone is moderate reddish brown (10R4/6); very fine grained; moderately sorted; subrounded; quartzose; highly calcareous; platy; 1 mm wide surface trails, sinuous and branching; phytosaur scrap. **0.6**

11 Mudstone (very slightly silty); moderate reddish brown (10 R 4/6); moderately calcareous. **1.5**

offset

10 Calcrete; moderate brown (5YR4/4); nodular; microcrystalline limestone; very laterally continuous. **3.0**

9 Siltstone and sandstone; siltstone is moderate reddish brown (10R4/6); structureless; highly calcareous; sandstone is 30-cm-thick layer 2 m from base of unit; sandstone is moderate reddish brown (10R4/6); very fine grained; moderately sorted; subrounded; ripple cross lamination; 8 mm diameter cylindrical, vertical burrows. **5.5**

8 Sandstone; moderate reddish brown (10R4/6); fine-very fine grained; poorly sorted; subrounded; quartzose; highly calcareous; structureless; pillowy. **0.5**

7 Silty mudstone; moderate reddish brown (10R4/6); highly calcareous; structureless. [interval of NMMNH localities 5, 36, 75] **2.0**

6 Sandstone; moderate reddish brown (10R4/6); very fine grained; poorly sorted; subrounded; quartzose; finely laminated; at 1.2 m from base of unit is 0.3 thick sandstone which is light greenish gray (5G8/1); very fine grained; poorly sorted; subrounded; quartzose; highly calcareous; platy, ripple laminar. **2.5**

offset [NMMNH locality 2 just above unit 5]

5 Sandstone and conglomerate; sandstone is moderate reddish brown (10 R 4/6)-light greenish gray (5GY8/1); fine-very fine grained; poorly sorted; subrounded; quartzose; platy; basal 10 cm is conglomerate; clasts are mainly light greenish gray (5GY8/1); limestone; matrix is like sandstone above but is coarse-very coarse grained; laterally at offset this unit is sandstone which is moderate reddish brown (10R4/6); fine-very fine grained; poorly sorted; subrounded; quartzose and lithic fragments; highly calcareous; bioturbated with 5 mm diameter cylindrical, vertical tubes. **1.1**

4 Silty mudstone and sandstone; silty mudstone is moderate reddish brown (10R4/6); moderately calcareous; sandstone is dark yellowish brown (10YR4/2); fine to very fine grained; poorly sorted; subrounded; quartzose; highly calcareous; ripple laminar; sandstone is top 30 cm of unit. **4.5**

3 Sandstone; moderate reddish brown (10R4/6); fine-medium grained; poorly sorted; subrounded; quartzose with lithic fragments; laminar and platy. **1.5**

2 Conglomerate; sandstone and siltstone; conglomerate is dark yellowish brown (10YR4/2); clasts are limestone up to 15 mm in diameter; matrix is sandstone; fine-coarse grained; poorly sorted; subrounded; quartzose; highly calcareous; sandstone is moderate brown (5YR3/4); fine-medium grained; poorly sorted; subrounded; quartzose with lithic fragments; laminated; siltstone is moderate reddish brown (10R4/6); highly calcareous; laminated; basal 1 m is conglomerate, overlying 2. 5 m is 20% sandstone 10% conglomerate 70% siltstone; conglomerates have many vertebrate fossils principally isolated phytosaur postcrania and *Typothorax* scute fragments. **3.5**

Trujillo Formation:

1 Sandstone; moderate brown (5YR4/4); medium grained well sorted; subrounded; quartzose with lithic fragments; highly calcareous; trough and planar crossbeds. **not measured**

REVUELTO CREEK, SECTION B

Section B was measured in NE1/4 NE1/4 SE1/4 Sec. 9, T10N, R33E.

unit lithology **thickness (m)**

Chinle Group: Bull Canyon Formation:

6 Soil. **0.6**

5 Siltstone and conglomerate; siltstone is pale red purple (5RP6/2) and small 1 mm diameter reduction spots of light greenish gray (5GY8/1); highly calcareous; conglomerate has pale brown (5YR5/2) clasts which are limestone and up to 6 mm in diameter; matrix is siltstone; pale red purple (5RP8/2); conglomerate is lens 0.15 m thick and contains bone pebbles. **0.6**

4 Siltstone; pale red purple (5RP6/2); highly calcareous; microbrecciated with stringers of grayish red purple (RP4/2). **1.5**

3 Conglomerate; clasts are pale red (5R6/2); limestone; matrix is sandstone pale green (5G7/2); fine-very fine grained; moderately sorted; subrounded; quartzose; highly calcareous. **0.3**

2 Siltstone; grayish red purple (5RP4/2); highly calcareous with floating pebbles (up to 2 mm in diameter) of very dusky red purple (5RP2/1); microbrecciated with small reduction spots of light greenish gray (5GY8/1); with 5 cm thick stringers of siltstone; dusky red (5R3/4); highly calcareous; main bone layer; unit is laterally discontinuous in scours. **0.3**

1 Conglomerate; clasts are light greenish gray (5G8/1); limestone; up to 18 mm in diameter; matrix is sandstone; moderate reddish brown (10R4/6); very fine grained; poorly sorted; well rounded; quartzose; conglomerate laterally continuous, thins laterally over 10 m to stacked lenses of conglomerate. **5.0**

0 Siltstone; moderate reddish brown (10R4/8) and locally grayish yellow green (5GY7/2); highly calcareous; structureless. **not measured**

REVUELTO CREEK, SECTION C

Section C was measured in NE1/4 NW1/4 SE1/4 Sec. 9, T10N, R33E, Quay County, New Mexico.

unit lithology **thickness (m)**

Chinle Group: Bull Canyon Formation:

24 Sandstone; pale yellowish green (10GY7/2); medium-fine grained; poorly sorted; well rounded; quartzose with lithic fragments; highly calcareous; ledge-former. **1.2**

23 Mudstone (slightly silty); moderate reddish brown (10R4/6); highly calcareous; lower 2.1 m has stringers of unit 22 lithology. **8.5**

22 Silty mudstone; pale yellowish green (10GY7/2); highly calcareous; erosional base. **0.15**

21 Mudstone (slightly silty); mottled light greenish gray (5G8/1) and grayish red purple (5RP4/2); highly calcareous. **1.8**

20 Conglomerate; clast are poorly sorted up to 18 mm in diameter; 70% limestone light olive gray (5Y6/1), 30% siltstone grayish red (10 R 4/1) and moderate reddish orange (10R4/6); matrix is sandstone; dark yellowish orange (10YR6/6); medium grained; poorly sorted; subrounded; quartzose; highly calcareous; ledge-former. **1.0**

19 Mudstone; pale red purple (5RP6/2); moderately calcareous; thins laterally to 0.3 m. **1.5**

18 Sandstone; greenish gray (5GY6/1); fine-very fine grained; poorly sorted; moderately rounded; quartzose; highly calcareous; local lenses of conglomerate (0.15 m thick) at base as 20. **0.30**

17 Sandstone; moderate brown (5YR3/4); fine to very fine grained; poorly sorted; subrounded; quartzose; highly calcareous. **0.8**

16 Conglomerate and sandstone; conglomerate has light olive gray (5Y6/1) clasts dominantly of limestone that are poorly sorted; matrix as 20; bone pebbles; sandstone is greenish gray (5GY6/1); fine grained; moderately sorted; well rounded; quartzose; highly calcareous; planar bedded; conglomerate grades up into sandstone. **1.05**

15 Mudstone; pale red purple (5RP6/2); very calcareous; scattered concretions of pale red purple (5RP6/2); highly calcareous; thins laterally over 10 m. **1.05**

14 Silty mudstone; pale red purple (5RP6/2); very calcareous. **0.6**

13 Silty mudstone; pale red purple (5RP6/2); very calcareous; calcareous concretions of pale red purple (5RP6/2) up to 0.3 x 1m; highly calcareous. **1.2**

12 Calcrete; moderate brown (5YR4/4); nodular; microcrystalline limestone; laterally continuous. **0.3**

11 Silty mudstone; pale red purple (5RP6/2); very calcareous; scattered concretions of pale red purple (5RP6/2); highly calcareous. **0.15**

10 Silty mudstone; reddish brown (10R4/6); very calcareous. **1.8**

9 Silty mudstone; pale red purple (5RP6/2); very calcareous; scattered concretions of pale red purple (5RP6/2); highly calcareous. **1.8**

8 Silty mudstone; reddish brown (10R4/6); very calcareous. **0.8**

7 Silty mudstone; pale red purple (5RP6/2); very calcareous; scattered concretions of pale red purple (5RP6/2); highly calcareous. **0.2**

6 Silty mudstone; reddish brown (10R4/6); very calcareous. **0.5**

5 Silty mudstone; pale red purple (5RP6/2); very calcareous; scattered concretions of pale red purple (5RP6/2); highly calcareous. **0.3**

4 Silty mudstone; moderate reddish brown (10R4/6); very calcareous. **3.0**

3 Siltstone and sandstone; siltstone is moderate reddish brown (10R4/6); highly

calcareous; sandstone from 3.0-4.5 from base of unit; sandstone is light greenish gray (5GY8/1); very fine grained; well sorted; moderately rounded; quartzose; highly calcareous; at 5.2 m calcareous cannonball concretions; at 6.7 m is 60 cm thick bed of siltstone; siltstone is moderate reddish brown (10R4/6) with small (1-2 mm diameter) reduction spots of light greenish gray (5GY8/1); at 7.9 m is 30 cm thick siltstone-very fine sandstone which is moderate reddish brown (10R4/6) with reduction spots (up to 3 mm diameter) of light greenish gray (5GY8/1); at 8.2-9.15 m is siltstone with concretions; siltstone is moderate reddish brown (10R4/6); concretions are light greenish gray (5G8/1) and up to 1 x 1.5 cm; both are highly calcareous. **9.15**

2 Siltstone; pale reddish brown (10R5/4) and pale red (10R6/2); highly calcareous; microbrecciated; wood locally and NMMNH locality. **2.5**

1 Mudstone and sandstone; moderate reddish brown (10R4/6). **not measured**

REVUELTO CREEK, SECTION D

Measured in NE1/4 NE1/4 SE1/4 sec. 16, T10N, R33E.

unit lithology **thickness (m)**

Chinle Group: Bull Canyon Formation:

9 Sandstone; pale red (5R6/2); very fine grained; moderately sorted; moderately rounded; quartzose; highly calcareous; contorted bedding and ripple lamination. **0.15**

8 Mudstone; pale red purple (5RP4/2); not calcareous; with siltstone stringers as unit 7 in basal 7.5 cm, 1.2 cm thick at 22 cm, 1.2 cm thick at 30 cm and 1 cm at 33 cm; laterally the basal siltstone thickens and coarsens to a conglomerate. **1.68**

7 Mudstone and siltstone; mudstone is slightly silty; pale yellowish green (10GY7/2) to pale red purple (5RP6/2); not calcareous; thin siltstone at 1.5 m from base; siltstone is light greenish gray (5GY8/1); highly calcareous; at 3 m from base are concretions like unit 6; many vertebrate fossils and coprolites (NMMNH locality 1). **5.8**

6 Concretions; moderate yellowish green (10GY6/4) unweathered, light olive gray (5Y5/2) weathered; highly calcareous; rounded concretions up to 15 cm x 10 cm. **0.15**

5 Siltstone; pale green (5G7/2) to pale red purple (5RP6/2); highly calcareous; in upper 7.5 cm are concretions which are muddy siltstone pale yellowish green (10GY7/2); highly calcareous. **2.0**

4 Sandstone and conglomerate; conglomerate clasts are pale green (5G7/2) and olive gray (5Y3/2); up to 10 mm in diameter; sandstone is mottled grayish red (10R4/2) and grayish red purple (5RP4/2); very fine grained; quartzose; highly calcareous; basal 3 cm is all conglomerate and above this is sandstone with scattered floating conglomerate clasts; conglomerate extends laterally up to 1.2 m. **1.2**

3 Siltstone; grayish red purple (5RP4/2); highly calcareous. **1.1**

2 Siltstone; grayish red purple (5RP8/1); moderately calcareous; stringers every 10-15 cm of sandstone; light greenish gray (5G8/1); very fine grained; well sorted; moderately rounded; quartzose; highly calcareous. **2.2**

1 Silty mudstone; moderate reddish brown (10R4/6); highly calcareous; 12.2-13.7 m from base are thin (0.5 cm thick) sandstone stringers; sandstone is light greenish gray (5GY8/1); very fine grained; well sorted; well rounded; quartzose; highly calcareous; ripple laminar. **16.75**