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REVIEW OF UPPER TRIASSIC STRATIGRAPHY AND BIOSTRATIGRAPHY IN THE CHAMA BASIN, NORTHERN NEW MEXICO

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Abstract.—Triassic strata in the Chama Basin of Rio Arriba County, New Mexico, pertain to the Upper Triassic Chinle Group (in ascending order, the Zuni Mountains, Shinarump, Salitral, Poleo, Petrified Forest and Rock Point formations). The base of the Chinle Group locally is the Zuni Mountains Formation (formerly "mottled strata"), a pedogenic weathering profile as much as 7 m thick, developed in the top of the Pennsylvanian-Permian Cutler Group. Where the Zuni Mountains Formation is absent, the base of the Chinle Group is the Shinarump Formation. In the Chama Basin, the Shinarump Formation (= Agua Zarca Formation of previous usage) is as much as 13 m thick and consists mostly of trough-crossbedded, quartzose sandstone and siliceous conglomerate. The Salitral Formation is as much as 31 m of mostly greenish and reddish brown, bentonitic mudstone. The Salitral Formation is divided into two members: a lower, Piedra Lumbre Member of greenish mudstone with a peristent sandstone bed (the El Cerrito Bed) at its top, and an upper, Youngsville Member, which mostly consists of reddish-brown mudstone. The Poleo Formation is up to 41 m thick and is mostly grayish yellow, trough-crossbedded litharenitic and subarkosic sandstone with minor amounts of both intrabasinal and siliceous conglomerate. Above the Poleo Formation, as much as 200 m of strata, dominated by reddish brown, bentonitic mudstone, constitute the Petrified Forest Formation. In the Chama Basin, the Petrified Forest Formation consists of two members, the lower Mesa Montosa Member, up to 24 m of thin-bedded sandstone, siltstone and mudstone, which is overlain by up to 176 m of the bentonitic mudstone-dominated Painted Desert Member. The Rock Point Formation in the Chama Basin disconformably overlies the Petrified Forest Formation and is as much as 70 m thick and mostly laterally persistent, repetitive beds of reddish brown and grayish red siltstone and ripple-laminar sandstone that essentially lack volcanic detritus.

In the Chama Basin, unionid bivalves from the Petrified Forest Formation are consistent with a Revueltian age, and palynomorphs from the Painted Desert Member of the Petrified Forest Formation and from the Rock Point Formation are of Norian age. Three formations of the Chinle Group in the Chama Basin contain biochronologically important vertebrate fossils, notably the aetosaur *Desmatosuchus haplocerus* (Adamanian) in the Salitral Formation, the aetosaurs *Typothorax coccinarum* and *Desmatosuchus chamaensis* and the phytosaur *Pseudopalatus buceros* (Revueltian) in the Petrified Forest Formation, and the phytosaur *Redondasaurus* (Apachean) in the Rock Point Formation. These fossils and lithostratigraphy allow precise correlation of the Chinle Group strata exposed in north-central New Mexico with other Upper Triassic strata in New Mexico.

INTRODUCTION

The Chama Basin of north-central New Mexico is a physiographic basin formed by the Chama River and its tributaries, especially the Rio Gallinas (Fig. 1). Located on the eastern edge of the Colorado Plateau, the Chama Basin is between the eastern margin of the structural San Juan Basin and the western edge of the Rio Grande rift. Outcrops in the Chama Basin are a thick, nearly flat-lying section of Permian and Mesozoic sedimentary rocks overlain in some areas by upper Cenozoic basalts and other volcanic rocks. A significant portion of this section is nonmarine red-bed siliciclastics of Late Triassic age. These are strata of the Chinle Group, and this article reviews the lithostratigraphy and biostratigraphy of Chinle Group strata in the Chama Basin.

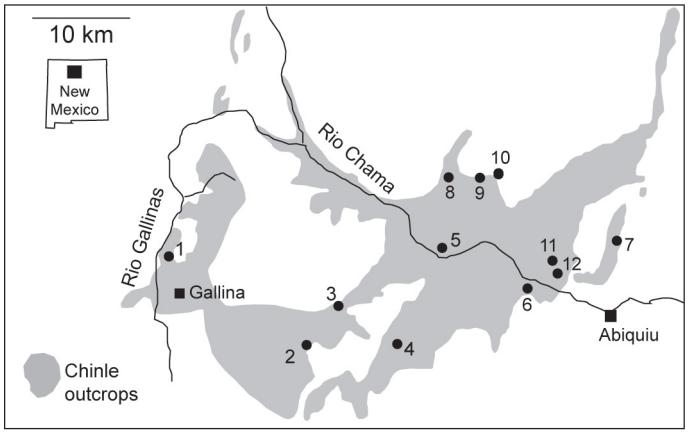

FIGURE 1. Map of the distribution of Chinle Group strata in the Chama Basin of north-central New Mexico (after Dane and Bachman, 1965) showing the locations of measured sections in this article. Locations are: 1 = Cerro Blanco, 2 = Mesa Montosa (type Agua Zarca, Salitral and Poleo formations, Mesa Montosa A and B sections), 3 = Coyote amphitheater, 4 = Youngsville landfill; 5 = Piedra Lumbre, 6 = Abiquiu Dam, 7 = Minas de Pedro, 8 = Snyder quarry, 9 = Canjilon quarry, 10 = Ghost Ranch *Coelophysis* quarry, 11 = Orphan Mesa, 12 = Rest Stop. The section at Chaves Box (Fig. 5) is located north of the map area. See Lucas et al. (2003a) for precise map coordinates of all of the measured sections.

PREVIOUS STUDIES

Scientific study of the Triassic strata in the Chama Basin began with the work of John Strong Newberry (1822-1892). In 1859, Newberry was appointed geologist of the San Juan Exploring Expedition lead by Captain J. N. Macomb (often referred to as the "Macomb Expedition"). The expedition set out from Santa Fe in early July 1859, heading to the junction of the Colorado and the Green Rivers in Utah. The expedition went up the Chama River by Abiquiu, then along Arroyo Seco and up the plateau to El Vado, Horse Lake and then on to Colorado, reaching Pagosa

Springs on July 28 (Newberry, 1876). Newberry thus was the first trained geologist to examine the Chama Basin.

Newberry's (1876) geological report on the expedition identifies the bedrock strata of the Chama Basin as Triassic, Cretaceous and Tertiary rocks. In the southern portion of the basin, Newberry climbed Capulin Mountain (he called it "Abiquiu Peak") and visited the old copper mines in El Cobre Canyon. In the roof of one of the mines, Newberry collected the first Triassic plant fossils with leaves discovered in the American West (Triassic fossil wood had been discovered in the 1840s: Ash, 1974). Newberry (1876) described and illustrated these plants and recognized their similarity to Triassic plants already known from Sonora, Mexico and from Virginia and North Carolina. He thus concluded (p. 69) that "we have, therefore, in these plants evidence of the Triassic age of *all* the variegated gypsiferous rocks of northern New Mexico; for the Lower Cretaceous sandstones immediately overlie the plant-beds of the *Cobre*." Newberry was correct about the Triassic age of the plants (they are from the Upper Triassic Shinarump Formation of the Chinle Group: Lucas and Hunt, 1992), but he was incorrect that Cretaceous sandstones immediately overlie them at El Cobre Canyon; the sandstones above the plant-bearing horizon are Upper Triassic Poleo Formation of the Chinle Group. Nevertheless, based on the fossils he collected in El Cobre Canyon, Newberry assigned what are now known to be Pennsylvanian-Permian (Cutler Group), Upper Triassic (Chinle Group) and Jurassic (Entrada, Todilto, Summerville and Morrison formations) strata to his "Triassic formation."

The next geological observations of the Triassic strata in the Chama Basin were made by Edward Drinker Cope (1840-1897), who traversed part of the basin in 1874 as a member of the Wheeler Survey of the U.S. Army (Simpson, 1951). Near Gallina (Fig. 1), Cope collected the first Upper Triassic vertebrate fossils discovered in the American West (including the type material of the aetosaur *Typothorax coccinarum* Cope), as well as the type specimens of the bivalves Meek (1875) named *Unio cristonensis*, *U. gallinensis* and *U. terraerubrae* (Lucas and Hunt, 1992; Hunt and Lucas, 1993a; Lucas et al., 2003b). Cope (1875, 1877) simply referred to the rocks that contained the fossils as Triassic, making no lithostratigraphic assignment. Several years later, a professional fossil collector hired by Cope, David Baldwin, collected additional vertebrate fossils from the Triassic of north-central New Mexico, including the type specimens of the phytosaur *Belodon buceros* and the dinosaur *Coelophysis* (Cope, 1881, 1887a,b, 1889; Huene, 1915; Padian, 1986; Colbert, 1974, 1989; Sullivan et al., 1996; Sullivan and Lucas, 1999; Lucas et al., 2002).

In an effort to follow up on the discoveries of Cope and Baldwin, E.C. Case, S.W. Williston and F. von Huene explored the Permian and Triassic in north-central New Mexico in 1911 (Case and Williston, 1912). Based on this expedition, Huene (1911) published a short article in which he described the Permian-Cretaceous section at "Mesa Poleo" (Mesa Montosa, just north of Arroyo del Agua of current maps). He coined the name "Poleo-top-sandstone" for the Triassic sandstone that caps the mesa (Lucas and Hunt, 1992, fig. 7), and thus introduced the first lithostratigraphic name for Triassic rocks in north-central New Mexico. Huene (1911) incorrectly correlated the "Poleo-top sandstone" to the "Shinarump Conglomerate," but correctly inferred that some of the strata immediately above the Poleo Formation in the Chama Basin are of Late Triassic age.

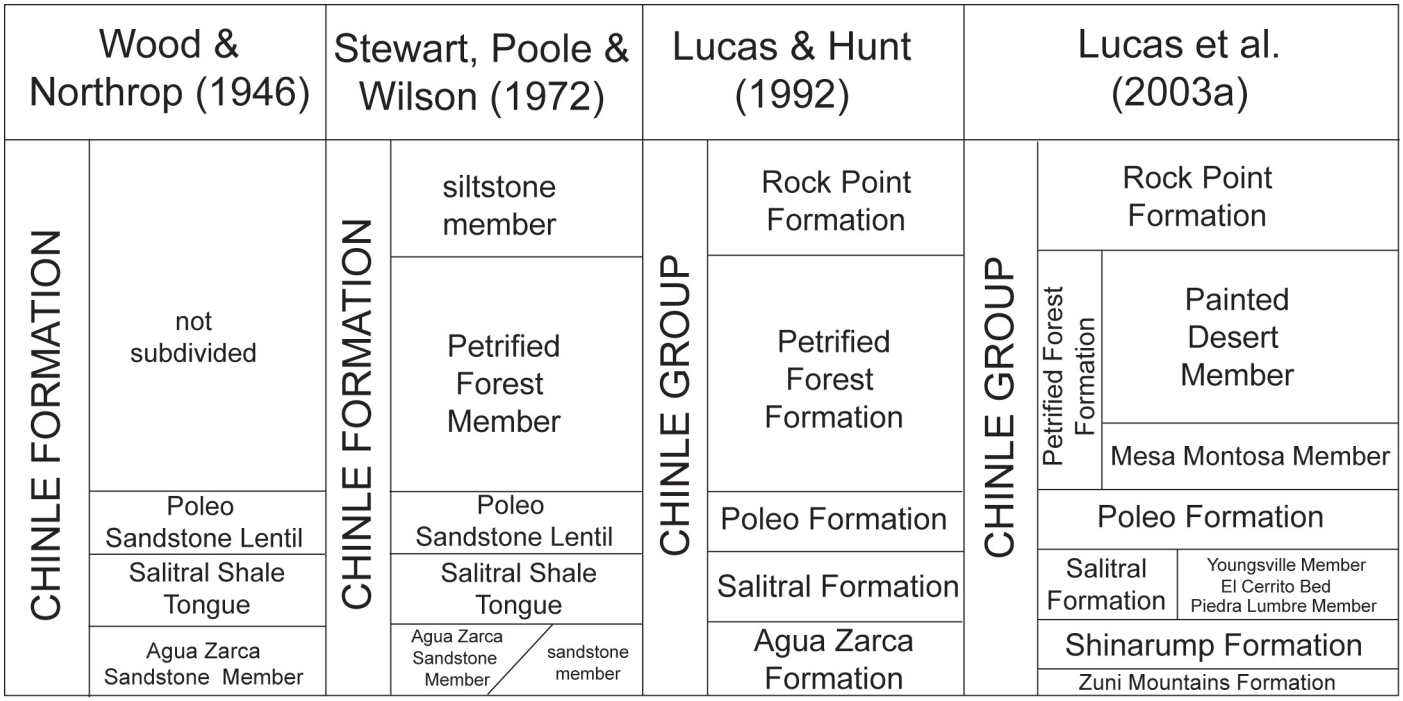

FIGURE 2. Development of lithostratigraphic nomenclature of Upper Triassic strata in the Chama Basin.

Wood and Northrop (1946) mapped the Triassic and adjacent strata in much of north-central New Mexico and assigned the Triassic rocks to the Chinle Formation of Gregory (1917). They named two new stratigraphic units for strata below Huene's (1911) Poleo, the "Agua Zarca sandstone member" and "Salitral shale tongue" of the Chinle Formation. They referred to the stratigraphic unit named by Huene (1911) as the "Poleo sandstone lentil" of the Chinle. The nomenclature introduced by Wood and Northrop (1946) was formally accepted by the U.S. Geological Survey (Keroher et al., 1966) and followed by subsequent authors, with recognition of two Chinle members above the Poleo: Petrified Forest Member overlain locally by the "siltstone member" (Smith et al., 1961; Stewart et al., 1972; O'Sullivan, 1974; Dubiel, 1989) (Fig. 2).

Kurtz (1978; see also Kurtz and Anderson, 1980) and Dubiel (1989) undertook sedimentological studies of the Triassic strata of north-central New Mexico. The discovery of the dinosaur quarry at Ghost Ranch (Colbert, 1947, 1950, 1964, 1974, 1989, 1990) and the nearby Canjilon phytosaur quarry (Camp, 1930; Lawler, 1976; Ballew, 1986, 1989; Hunt and Lucas, 1989; Long et al., 1989; Hunt and Downs, 2002; Martz, 2002a, b) demonstrated the great paleontological potential of the strata first collected by Cope and Baldwin. More recent publications on the paleontology of the Triassic in north-central New Mexico include Ash (1974), Litwin (1986), Padian (1986), Colbert (1989, 1990), Hunt and Lucas (1989, 1991), Litwin et al. (1991), Berman and Reisz (1992), Lucas and Hunt (1992), Hunt and Lucas (1993a), Sullivan et al. (1996), Heckert et al. (1999a, b, 2000a), Harris and Downs (2002), Martz (2002b), Lucas et al. (2002), Small and Downs (2002), Zeigler et al. (2002a, b, c), Heckert and Lucas (2002b) and Zeigler (2002). One of the most important Chinle quarries discovered since the Ghost Ranch *Coelophysis* quarry is the Snyder quarry, in the Painted Desert Member of the Petrified Forest Formation. This quarry is extraordinarily rich, containing the disarticulated remains of numerous invertebrates and invertebrates that have been the focus of much study (Heckert et al., 2000b, 2003a, b; Zeigler et al., 2002a, b, 2003a,b,c,d,e; Heckert and Zeigler, 2003; Hurlburt et al., 2003; Lucas et al., 2003a,b; Rinehart et al., 2003; Tanner et al., 2003; Zeigler, 2002, 2003; Jenkins, 2004; Jenkins and Heckert, 2004a,b; Heckert and Jenkins, 2005).

Lucas and Hunt (1992; Lucas, 1993; Hunt and Lucas, 1993a; Sullivan et al., 1996) revised the Upper Triassic lithostratigraphy in the Chama Basin. They assigned the section to the Chinle Group divided into the (ascending order) Agua Zarca, Salitral, Poleo, Petrified Forest and Rock Point formations. Lucas et al. (2003a) modified and further subdivided this lithostratigraphy (Fig. 2), and their stratigraphic nomenclature is employed here.

LITHOSTRATIGRAPHY

Following Lucas et al. (2003a), we assign all Upper Triassic strata in the Chama Basin to six formations of the Chinle Group (in ascending order): Zuni Mountains, Shinarump, Salitral, Poleo, Petrified Forest and Rock Point formations (Figs. 2-7).

Zuni Mountains Formation

In the Chama Basin, strata formerly termed "mottled strata" (Stewart et al., 1972; Lucas and Hunt, 1992; Hunt and Lucas, 1993a) were assigned to the Zuni Mountains Formation of Heckert and Lucas (2003) by Lucas et al. (2003a). These strata are pedogenically modified siltstone, mudstone and sandstone beneath the Shinarump Formation. On the Colorado Plateau, they represent a paleoweathering profile developed on sub-Chinle Permian or Triassic strata, and Heckert and Lucas (2003) formally designated the "mottled strata" of prior usage the Zuni Mountains Formation, with a type section in the Zuni Mountains of west-central New Mexico, southwest of the Chama Basin.

In the Chama Basin, the Zuni Mountains Formation is relatively thin, as much as 7 m thick, and usually absent (Fig. 3); at most places the Shinarump Formation rests disconformably on the underlying Pennsylvanian-Permian Cutler Group. Where locally present, such as at Mesa Montosa (Fig. 3), the Zuni Mountains Formation is sandy mudstone, siltstone and sandstone that is color mottled various shades of purple, orange, gray, yellow, green and brown (Lucas and Hunt, 1992). These color-mottled strata grade downward into Cutler red beds. Thus, Zuni Mountains strata in the Chama Basin are genetically Cutler strata, subsequently modified pedogenically and mapped with Chinle Group strata. They are the product of a weathering profile developed during the Tr-3 hiatus (Lucas, 1993), and are widespread across the Colorado Plateau (e.g., Stewart et al., 1972; Lucas, 1993; Heckert and Lucas, 2003), so the presence of the Zuni Mountains Formation in the Chama Basin is not surprising.

Shinarump Formation

Above local outcrops of the Zuni Mountains Formation, the base of the Chinle Group in the Chama Basin is a pervasive sheet of quartzose sandstone, conglomeratic sandstone and siliceous, extraformational conglomerate. Wood and Northrop (1946) named this unit the Agua Zarca sandstone member of the Chinle Formation, and subsequent workers (e.g., Smith et al., 1961; Stewart et al., 1972; O'Sullivan, 1974; Dubiel, 1989; Lucas and Hunt, 1992; Hunt and Lucas, 1993a; Lucas, 1993) have continued to use that name. However, Lucas et al. (2003a) abandoned the name Agua Zarca and replaced it with the older name Shinarump Formation. Shinarump is used as a formation name in west-central New Mexico, and in eastern Arizona and southwestern Utah (e.g., Stewart et al., 1972), and the unit called Shinarump in these regions clearly is correlative to the Agua Zarca of the Chama Basin (Stewart et al., 1972; Lucas, 1993; Heckert and Lucas, 2003). Furthermore, both units are of identical lithotypes (quartzose sandstone, conglomeratic sandstone, and silica-pebble conglomerate). It thus serves no useful purpose to perpetuate the name Agua Zarca; it is an unnecessary local synonym of Shinarump.

In the Chama Basin, the Shinarump Formation is as much as 13 m thick (Fig. 3). Trough crossbeds are the dominant bedform, and sandstone petrology is mature (quartzose). Colors are mostly

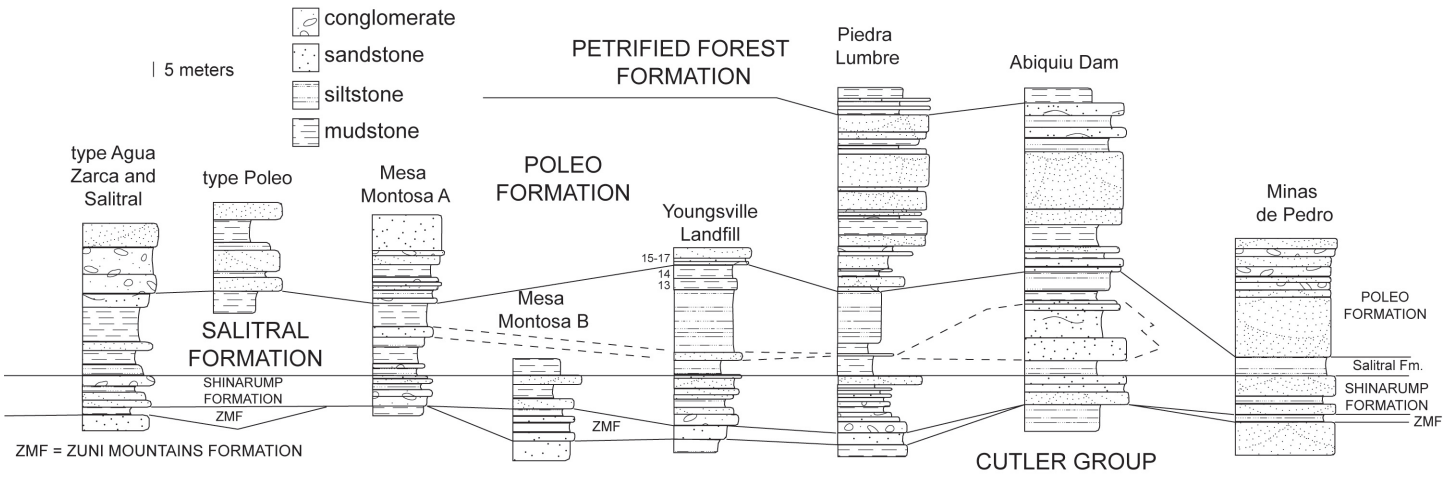

FIGURE 3. Measured stratigraphic sections of the lower Chinle Group (Zuni Mountains, Shinarump, Salitral and Poleo formations) in the Chama Basin. See Figure 1 for locations of measured sections.

greenish gray and grayish yellow, but in some locations (such as our Youngsville landfill and Piedra Lumbre sections), pale red, pale orange and moderate brown colors are also present. This color variation mostly reflects local mineralization (copper, uranium) that produces colors that range from black to yellow to green. Indeed, stratiform copper was mined long ago on a small scale from the Shinarump Formation in El Cobre Canyon (Newberry, 1876). In the Chama Basin, petrified logs and other pieces of silicified wood are locally common in the Shinarump Formation.

The Shinarump Formation across the Chama Basin forms a light-colored ledge, bench or cliff at the base of the Chinle Group. Its basal contact is a sharp, erosional scour on underlying finer grained strata of the Zuni Mountains Formation or of the Cutler Group. However, at Chaves Box (Fig. 5), the Shinarump rests on Precambrian basement or a thin interval of marine Pennsylvanian strata (Muehlberger, 1967). This is one of the most profound expressions of the Tr-3 unconformity at the base of the Chinle Group (Pipiringos and O'Sullivan, 1978; Lucas, 1993; Lucas et al., 1997). The upper contact of the Shinarump Formation is fairly sharp as well, where mudstone at the base of the Salitral Formation rests directly on sandstone or conglomeratic sandstone of the Shinarump Formation. Whether or not this upper contact of the Shinarump Formation is a substantial disconformity cannot be determined without additional age control.

Salitral Formation

Wood and Northrop (1946) introduced the term "Salitral shale tongue" for strata between the Shinarump and Poleo formations in the Chama Basin. We continue to use this name as Salitral Formation, following Lucas and Hunt (1992) and Lucas et al. (2003a).

In terms of regional Chinle Group stratigraphy, the Salitral Formation occupies the same stratigraphic interval as the Bluewater Creek Formation and the Blue Mesa Member of the Petrified Forest Formation in west-central New Mexico, and the Monitor Butte Formation and Blue Mesa Member of the Petrified Forest Formation in southeastern Utah (Lucas and Heckert, 1995, 1996; Lucas et al., 1997, 1999; Heckert and Lucas, 2003). This homotaxis suggests that the Salitral is equivalent to one or more of these units, but it is not a synonym of one of these units. This is because the Salitral Formation is a much thinner unit than its equivalents and preserves a succession of lithotypes - green mudstone, overlain by persistent sandstone capped by red mudstone - different from its homotaxial equivalents. The Salitral Formation in the Chama Basin thus remains a distinctive, mappable lithofacies of the lower Chinle Group that also crops out along the southern flank of the Nacimiento uplift and as far east as the Hagan basin-Placitas area near Albuquerque (Lucas and Heckert, 1995, 1996; Lucas et al. 1999; Van Hart, 1999).

Detailed lithostratigraphy of the Salitral Formation in the Chama Basin indicates it can be divided into three units, two members and a bed (Lucas et al., 2003a).

Piedra Lumbre Member

The lower part of the Salitral Formation is olive gray and brown sandstone and silty mudstone. This interval, up to 5 m thick at the type section (units 9-11 of the Youngsville landfill section: Fig.4), forms a prominent "green" slope or hill shoulder immediately above the Shinarump Formation. Lucas et al. (2003a) named this interval the Piedra Lumbre Member for the Piedra Lumbre Land Grant, near the type section. The upper bed of the Piedra Lumbre Member is a distinctive brown-to-yellow bench of intraformational conglomerate, as much as 1.6 m thick (Fig. 4). Lucas et al. (2003a) named this the El Cerrito Bed of the Piedra Lumbre Member (Fig. 3). El Cerrito is a small hill just south of the type section.

Youngsville Member

Most of the upper part of the Salitral Formation is reddish brown, bentonitic mudstone. It forms a prominent red-to-purple

slope and is as much as 26 m thick below the overlying bench- or cliff-forming Poleo Formation. Lucas et al. (2003a) named this unit the Youngsville Member of the Salitral Formation for the village of that name near the type section (Figs. 3-4).

Discussion

Throughout the Chama Basin, the Salitral Formation forms a mudstone-dominated slope between the cliff/ledge-forming Shinarump (below) and Poleo (above) formations. Salitral sections are dominantly green, purple and red bentonitic mudstone with calcrete nodules; conglomerate and sandstone, other than the locally persistent El Cerrito Bed, are minor lithotypes.

The two members of the Salitral Formation named by Lucas et al. (2003a) can be traced over much of the Youngsville, Arroyo del Agua and Echo Amphitheater 7.5-minute quadrangles. In some other parts of the Chama Basin, however, this member-level subdivision in not clear, largely because the Salitral Formation usually forms covered or deeply weathered slopes (Fig. 3).

The Salitral Formation contact with the underlying Shinarump Formation, as noted above, is a sharp surface where mudstone rests directly on sandstone or conglomeratic sandstone. Nevertheless, sandstone beds in the lower Salitral lithologically resemble Shinarump sandstones. This suggests that the Shinarump-Salitral contact may be conformable.

The Poleo Formation contact on the Salitral Formation is a sharp, scoured surface where conglomerate/sandstone at the base of the Poleo is incised into underlying Salitral mudstone/siltstone (Fig. 3). This is the Tr-4 unconformity of Lucas (1993). Dubiel's (1989, fig. 17) schematic depiction of interfingering of the Poleo and underlying Salitral thus lacks a factual basis, as everywhere that the two units crop out the Poleo base is a sharp, scoured surface into the underlying Salitral (Fig. 3).

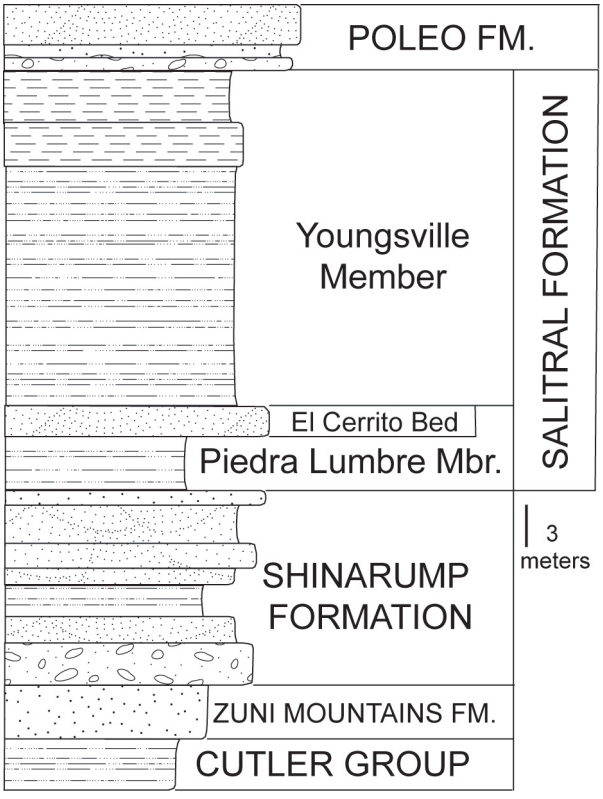

FIGURE 4. Youngsville landfill section, the type section of the Piedra Lumbre Member, El Cerrito Bed and Youngsville Member of the Salitral Formation. See Figure 1 for location of measured section.

Poleo Formation

The distinctive, medial sandstone unit of the Chinle Group in the Chama Basin is the Poleo Formation of Huene (1911). This unit is homotaxial to the other extensive medial sandstone sheets of the Chinle Group – the Trujillo Formation of West Texas and eastern New Mexico, the Sonsela Member of the Petrified Forest Formation in west-central New Mexico and northeastern Arizona and the Moss Back Formation of southern Utah and southwestern Colorado (Lucas, 1993; Heckert and Lucas, 1996, 2003; Lucas et al., 1997, 1999, 2001). The Poleo Formation is exposed throughout the Chama physiographic basin, along the flanks of the Nacimiento Mountains and in the Jemez Mountains of north-central New Mexico (Lucas and Hunt, 1992; Lucas and Heckert, 1995, 1996). Its relatively great local thickness, grayish yellow coloration, micaceous litharenite petrography and mixed conglomerate-clast lithotypes (both intrabasinal sedimentary clasts and extrabasinal siliceous clasts) serve to distinguish the Poleo Formation from its homotaxial equivalents.

The Poleo Formation in the Chama Basin is as much as 41 m thick, and the unit is almost exclusively composed of sandstone, conglomeratic sandstone and conglomerate (Figs. 3, 5). Poleo sandstones are micaceous litharenites and are typically grayish yellow in color. Conglomerates are either intrabasinal (composed of siltstone and nodular calcrete clasts) or extrabasinal (chert and quartzite clasts).

The Poleo has a sharp, scoured contact on the underlying Salitral Formation, as noted above. It grades upward into the overlying Petrified Forest Formation. Throughout the Chama Basin, the Poleo Formation forms a light-colored bench, ledge or cliff. Most striking is the Poleo outcrop at Abiquiu Dam (Fig. 3), where the complex internal stratigraphy of the Poleo Formation is well revealed by the engineering geological profile at the dam abutment (Lucas et al., 2003a, fig. 8).

The Poleo also has an inverse thickness relationship with the underlying Salitral Formation. Where the Poleo Formation is relatively thick, the Salitral Formation is relatively thin and vice versa. We interpret this to indicate that relatively thick Poleo sections are valley fills cut into the underlying Salitral during the development of the Tr-4 unconformity.

Petrified Forest Formation

The thickest formation of the Chinle Group in the Chama Basin is the Petrified Forest Formation. As much as 200 m thick, this unit is dominantly reddish-brown bentonitic mudstone that forms extensive slopes and dissected badland areas where exposed. Lucas et al. (2003a) divided the Petrified Forest Formation in the Chama Basin into two members, a lower, Mesa Montosa Member

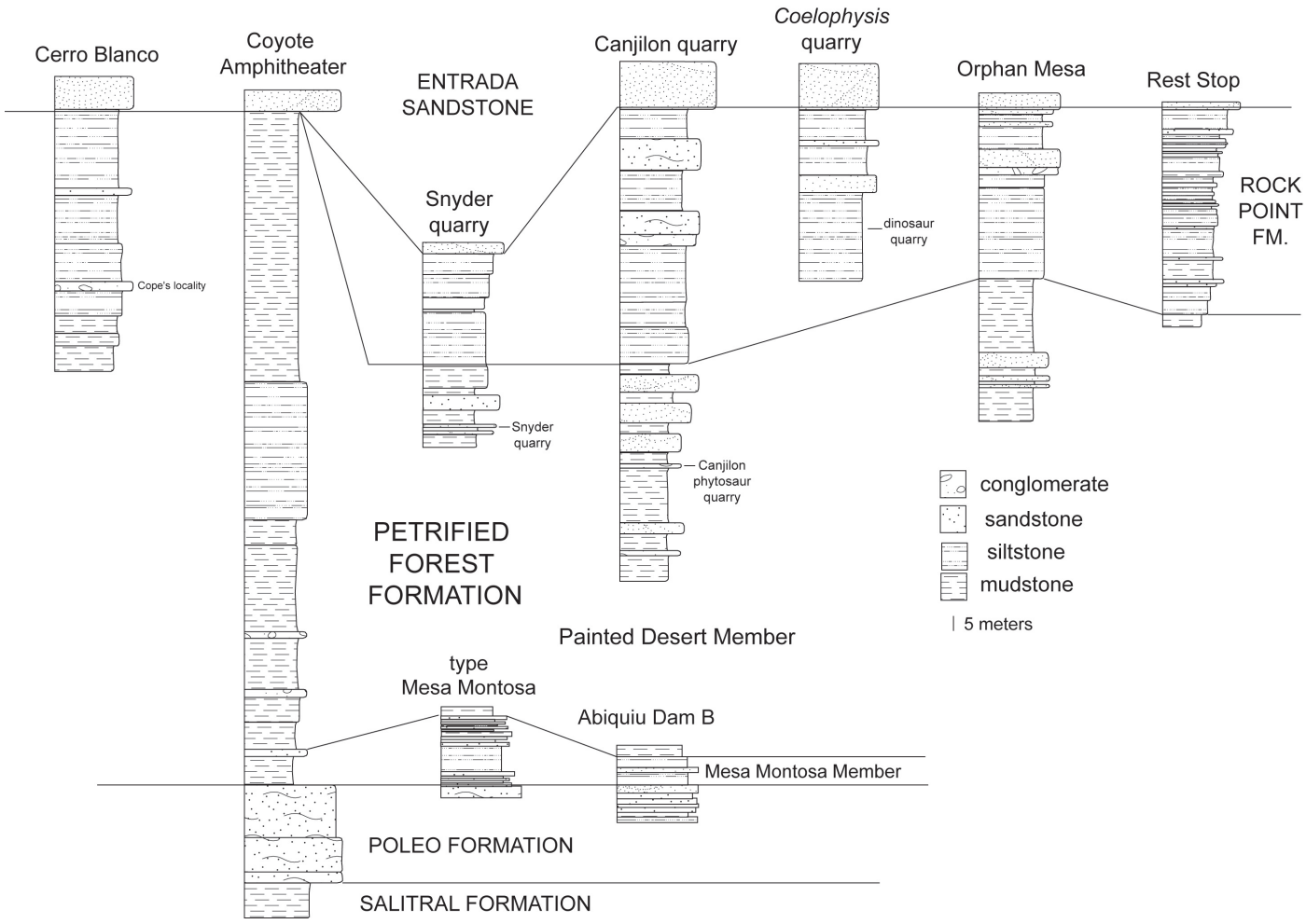

FIGURE 5. Measured stratigraphic sections of the upper Chinle Group (Petrified Forest and Rock Point formations) in the Chama Basin. See Figure 1 for locations of measured sections.

and an upper, Painted Desert Member, a unit that has long been recognized on the Colorado Plateau (e.g., Stewart et al., 1972; Lucas, 1993).

Mesa Montosa Member

The lower part of the Petrified Forest Formation in the Chama Basin is a sandstone-dominated unit that Lucas et al. (2003a) named the Mesa Montosa Member for the mesa of that name near the type section. At the type section, the Mesa Montosa Member is 22 m thick and mostly sandstone (44% of the measured section) and mudstone (35% of the section), with a lesser proportion of siltstone (20% of the section) (Fig. 5). These lithotypes range in color from reddish brown to moderate brown, and sandstone beds are typically ripple laminated to laminated and thin bedded. The Mesa Montosa Member thus forms a ribbed slope, 4 to 24 m thick, between coarser-grained Poleo Formation sandstone below and slope-forming mudstone of the Painted Desert Member of the Petrified Forest Formation above (Fig. 5).

The Mesa Montosa Member is widely distributed in the Chama Basin. We have measured sections of this unit from its type section near Coyote to the Piedra Lumbre Land Grant and Abiquiu Dam to the east, and to Chaves Box to the north (Figs. 5-6).

Painted Desert Member

Lucas et al. (2003a) applied the name Painted Desert Member to the upper, mudstone-dominated portion of the Petrified Forest Formation in the Chama Basin. In the Chama Basin, the Painted Desert Member is as much as 176 m thick and mostly reddish brown betonitic mudstone. Lucas (1993) introduced the name Painted Desert Member of the Petrified Forest Formation for the super-Sonsela portion of the formation in the Petrified Forest National Park in eastern Arizona.

Subsequent work has demonstrated the lithostratigraphic and biostratigraphic basis for recognition of the Painted Desert Member in west-central and central New Mexico, and throughout the Four Corners area (e.g., Lucas et al., 1997, 1999; Heckert and Lucas, 2002a, b, c, 2003). Similarly, strata here assigned to the Painted Desert Member in the Chama Basin: (1) occupy the same stratigraphic position as the type Painted Desert Member; (2) are lithologically similar to the type Painted Desert Member; and (3)

like the type Painted Desert Member, yield tetrapod fossils of Revueltian age and palynomorphs deemed Norian (see below). Therefore, extension of the term Painted Desert Member into the Chama Basin is fully justified (Lucas et al., 2003a).

The Painted Desert Member comprises the bulk of the Petrified Forest Formation in the Chama Basin. Its base is a thick mudstone bed above the highest sandstone/siltstone ledge of the Mesa Montosa Member. Its top is a sharp contact with siltstone/sandstone of the Rock Point Formation, or locally, sandstone of the Jurassic Entrada Sandstone rests directly on the Painted Desert Member (Fig. 5). The Petrified Forest-Rock Point contact is marked by the change from mudstone to overlying siltstone/sandstone and the change from bentonitic strata to overlying strata that lack significant volcanic detritus.

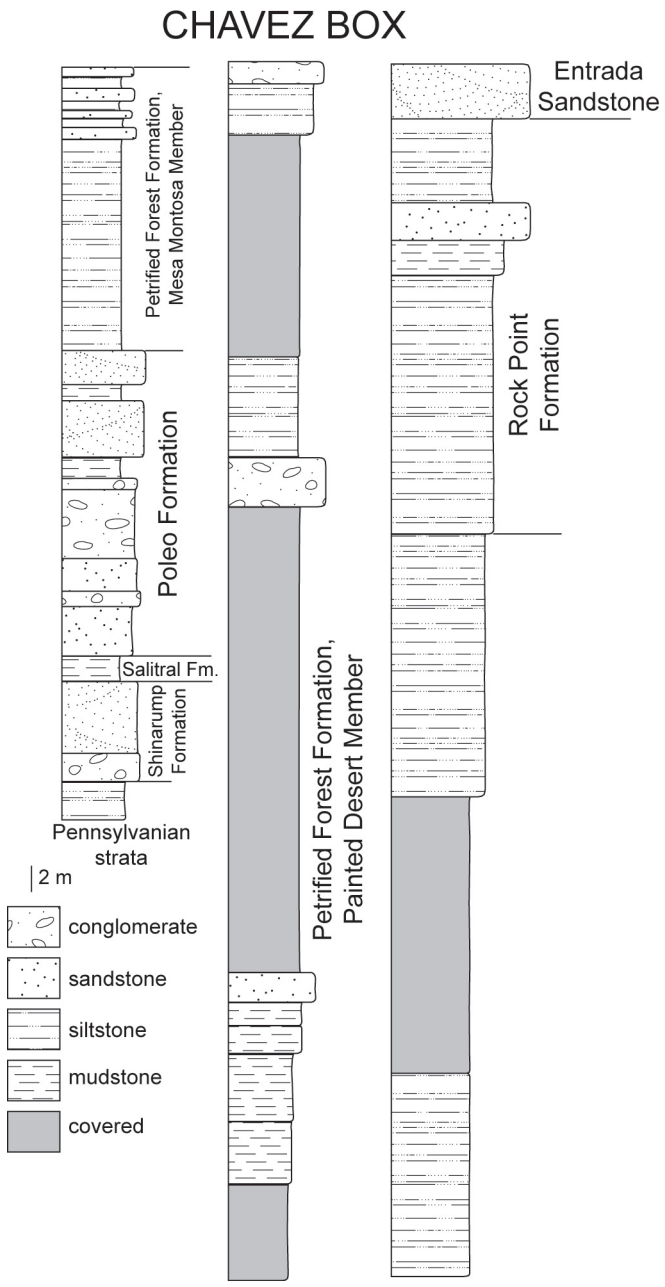

FIGURE 6. Chinle Group section at Chaves Box

Rock Point Formation

The stratigraphically highest unit of Triassic age in the Chama Basin is the Rock Point Formation. Rock Point strata are as much as 70 m thick and consist mostly of reddish brown and grayish red beds of massive siltstone and fine sandstone. The thinly interbedded sandstone and siltstone beds form a ribbed cliff where the Rock Point outcrop is not deeply weathered. Where weathered, the Rock Point Formation is an orange slope.

The Rock Point base is the first persistent bed of fine-grained sandstone above slope forming mudstone of the Painted Desert Member of the Petrified Forest Formation. The top of the Rock Point is a sharp contact with overlying eolian sandstone of the Slick Rock Member of the Jurassic Entrada Sandstone (Lucas and Anderson, 1998).

Identification of the Rock Point Formation in the Chama Basin is well supported because: (1) it closely resembles the type Rock Point strata in the Four Corners region; (2) Rock Point strata in the Chama Basin are at the top of the Chinle Group, as they are elsewhere; and (3) Rock Point strata at Ghost Ranch yield Apachean-age vertebrate fossils. Stewart et al. (1972) recognized this correlation, equating the "siltstone member" (our Rock Point Formation) and the Rock Point Formation elsewhere. Dubiel (1989), however, assigned these strata to the Owl Rock Formation (Member) as a lake margin facies of that unit. Lucas and Hunt (1992, p. 158) presented a detailed refutation of Dubiel's assignment, and subsequent work on Owl Rock sedimentology (Tanner, 2000) has rejected the sedimentological model of Owl Rock deposition advocated by Dubiel (1989).

Despite this, Goldstein and colleagues, in a series of abstracts (Goldstein et al., 1996; Hargrave et al., 1996; Trinh et al., 1996), continued to assign uppermost Chinle Group strata in the Ghost Ranch area to the Owl Rock Formation. Our reading of these abstracts and discussion with B. Goldstein indicate that they are based on a lack of knowledge of regional Chinle Group stratigraphy and biostratigraphy, an inability to discriminate lithotypes accurately and a basic inability to trace beds laterally in the essentially flat-lying badland exposures in and around Ghost Ranch (also see Sullivan et al., 1996). Thus, the work of Goldstein and colleagues does not contribute to an understanding of Chinle Group stratigraphy in the Chama Basin.

BIOSTRATIGRAPHY

Fossil plants, invertebrates and vertebrates have been collected from Chinle Group strata in the Chama Basin since the 1800s. Here, we review the stratigraphic distribution of fossils from the Chinle Group in the Chama Basin.

Shinarump Formation

The only fossils known form the Shinarump Formation in the Chama Basin are fossil plants (both leaves and wood) origi-

nally reported by Newberry (1876) and reviewed by Ash (1974). These are from abandoned copper mines (Minas de Pedro and Las Minas Jimmie) in El Cobre Canyon. Ash (1974) listed the flora as *Brachyphyllum* sp., *Pagiophyllum newberryi*, *Araucarioxylon arizonicum*, *Otozamites macombi*, *O. powelli* and *Zamites occidentalis*. These plants belong to the *Dinophyton* floral zone of Ash (1980), which occurs in strata of Otischalkian-Adamanian age throughout the Chinle Group (Lucas, 1997).

Salitral Formation

Lucas and Hunt (1992) and Hunt and Lucas (1993a) documented a small assemblage of tetrapod fossils from the Youngsville Member of the Salitral Formation at the formation type section. Besides coprolites and indeterminate metoposaurid and phytosaur remains, these fossils include a paramedian scute that they assigned to the aetosaur *Longosuchus* (Hunt and Lucas, 1990, fig. 3I-J) and a theropod dinosaur vertebra (Heckert et al., 2000a, fig. 3A-C) (Table 1). The presence of *Longosuchus* suggests an Otischalkian age, but Lucas et al. (2003a) concluded that the specimen is better assigned to *Desmatosuchus* as *D.* cf. *D. haplocerus*. This suggests an Adamanian age (cf. Heckert et al., 2003a). Recent collecting by us in the Salitral Formation reveals additional fragmentary fossils of phytosaurs, aetosaurs and metoposaurids (Lucas et al., 2003a).

Poleo Formation

Abundant pieces of petrified wood, mostly oxidized, are present in the Poleo Formation. Fragments of vertebrate bone, mostly unidentifiable, are also present in some conglomerate beds of the Poleo. Thus, no biostratigraphically useful fossils are yet known from the Poleo Formation in the Chama Basin.

TABLE 1. Tetrapod faunas of the Chinle Group in the Chama Basin.

Salitral Formation (Youngsville Member):	
Metoposaur	*Buettneria*
Phytosaurs	Indeterminate
Aetosaur	*Desmatosuchus*
Dinosaur	Theropoda
Petrified Forest Formation (Painted Desert Member):	
Amphibians	Metoposauridae indet.
Phytosaurs	*Pseudopalatus buceros*
Aetosaurs	*Typothorax coccinarum* *Desmatosuchus chamaensis*
Rauisuchians	*Postosuchus*
Theropod dinosaur	*Eucoelophysis baldwini*
Reptilia	Cynodontia Lepidosauromorpha *Dolabrosaurus*
Rock Point Formation:	
Phytosaur	*Redondasaurus bermani*
Archosauromorphs	*Vancleavea* Drepanosaurid
Rauisuchian	*Postosuchus kirkpatricki*
Theropod dinosaur	*Coelophysis bauri*

Petrified Forest Formation

In the Chama Basin, the unionid bivalves from the Painted Desert Member of the Petrified Forest Formation (Meek, 1875; Good, 1998; Lucas et al., 2003b) are of some biostratigraphic significance. Good (1993a,b, 1998) proposed a molluscan zonation of the Chinle Group consisting of two zones: the *Antediplodon graciliratus* zone of early Revueltian age, and the *A. thomasi* zone of late Revueltian age.

Unionids originally described by Meek (1875) from the Painted Desert Member of the Petrified Forest Formation near Gallina in the Chama Basin (Lucas and Hunt, 1992) pertain to taxa found elsewhere in Revueltian strata of the Chinle Group in New Mexico, Arizona and Utah (Good, 1998). So, the Painted Desert Member unionids from the Chama Basin are consistent with (though not demonstrative of) a Revueltian age based on vertebrate biostratigraphy.

A small, fragmentary vertebrate fossil assemblage was collected from the Mesa Montosa Member in its type area. It includes the Revueltian index taxa *Pseudopalatus buceros* and *Typothorax coccinarum* (Lucas and Hunt, 1992).

A much more extensive Revueltian-age vertebrate fossil assemblage is present in the upper part of the Painted Desert Member at several locations and is reviewed in detail by Heckert et al. (this volume). Especially significant are: (1) Cope and Baldwin's localities near Gallina (Cope, 1875, 1877, 1881, 1887a,b, 1889; Lucas and Hunt, 1992; Hunt and Lucas, 1993a); (2) the Snyder quarry near Ghost Ranch (Heckert et al., 2000a, b; Zeigler, 2002; Zeigler et al., 2002a, b, 2003a; Heckert and Jenkins, 2005); (3) the Canjilon phytosaur quarry (Camp, 1930; Lawler, 1976; Long et al., 1989; Martz, 2002a, b; Hunt and Downs, 2002; Zeigler et al., 2002c); and (4) the Orphan Mesa area (Sullivan et al., 1996; Sullivan and Lucas, 1999). The tetrapod fauna of the Painted Desert Member (Table 1) includes the phytosaur *Pseudopalatus* and the aetosaurs *Desmatosuchus chamaensis* and *Typothorax coccinarum*, index taxa of the Revueltian lvf.

Rock Point Formation

Pollen from the Rock Point Formation is considered to be of Norian age (Litwin, 1986; Litwin et al., 1991). The vertebrate fossil assemblage (Table 1) from the Whitaker quarry at Ghost Ranch includes *Redondasaurus*, an index taxon of the Apachean land-vertebrate faunachron (Hunt and Lucas, 1993b; Lucas et al., 1997).

Hunt and Lucas (1993a; also see Lucas 1998) suggested the Apachean is equivalent to the Rhaetian, largely based on a stage-of evolution correlation using phytosaurs. However, more recent data, especially the presence of the Norian aetosaur *Aetosaurus* in the Rock Point Formation (Small, 1998), suggest the unit is of Norian age. This brings the vertebrate biostratigraphy into

agreement with the palynostratigraphy, though a precise age of the Rock Point Formation within the Norian is not readily determined; it is probably late Norian.

CORRELATION

Our regional correlation of the Chinle Group section in the Chama Basin is based primarily on lithostratigraphy, and is supported by biostratigraphy (Fig. 7). In west-central New Mexico, the Zuni Mountains and Shinarump formations are thin units generally mapped together (Stewart et al., 1972; Lucas, 1993; Heckert and Lucas, 2002b, 2003; Anderson et al., 2003). Across west-central and north-central New Mexico, the Shinarump Formation is laterally continuous and thickens substantially to the east of the Chama Basin, where it is correlative with the Santa Rosa Formation, which is divisible into three members (Fig. 7) (Lucas et al., 1999). The Santa Rosa Formation then thins dramatically eastward, so that at Palo Duro Canyon in West Texas it equivalent to a relatively thin unit, the Camp Springs Formation (Lucas et al., 2001). It is likely that there was a depositional center focused near Lamy and Tucumcari during deposition of the Shinarump and Santa Rosa formations. Similarly, some of the thickest sections of the Shinarump (= Agua Zarca) Formation are just south of the Chama Basin in the Nacimiento uplift (e.g., Lucas and Hunt, 1992; Lucas and Heckert, 1996). This suggests that this area may have been the location of a large, northwest-trending paleovalley during Otischalkian time.

The Salitral Formation is equivalent to the Bluewater Creek Formation and the Blue Mesa Member of the lower Petrified Forest Formation to the west (Heckert and Lucas, 2002b, c, 2003) and the Garita Creek and Tecovas formations to the east (Lucas et al., 1999, 2001) (Fig. 7). This stratigraphic interval is relatively uniform in its thickness and is thinnest in the Chama Basin section. Sandstones are more prevalent to the west and to the east, while the central sections are either composed entirely of mudstone, or have very thin, sporadic sandstone beds. In general, the Piedra Lumbre Member most resembles basal Bluewater Creek strata (west). The El Cerrito Bed occupies a similar stratigraphic position to the McGaffey Member of the Bluewater Creek Formation (Anderson and Lucas, 1993; Heckert and Lucas, 2002b, 2003), but we cannot demonstrate a direct correlation. The Youngsville Member most closely resembles upper Bluewater Creek strata (west).

Equivalent to the Sonsela Member of the Petrified Forest Formation to the west and to the Trujillo Formation to the east, the Poleo Formation and its equivalents are variable in thickness, though generally thicker to the east (Fig. 7). To the west, the Poleo and its equivalents are thick, multistoried sandstones, whereas to the east, this interval contains relatively thick mudstone units.

The Petrified Forest Formation is the thickest of all of the Upper Triassic units in the Chama Basin and is equivalent to the Painted Desert Member of the Petrified Forest Formation to the

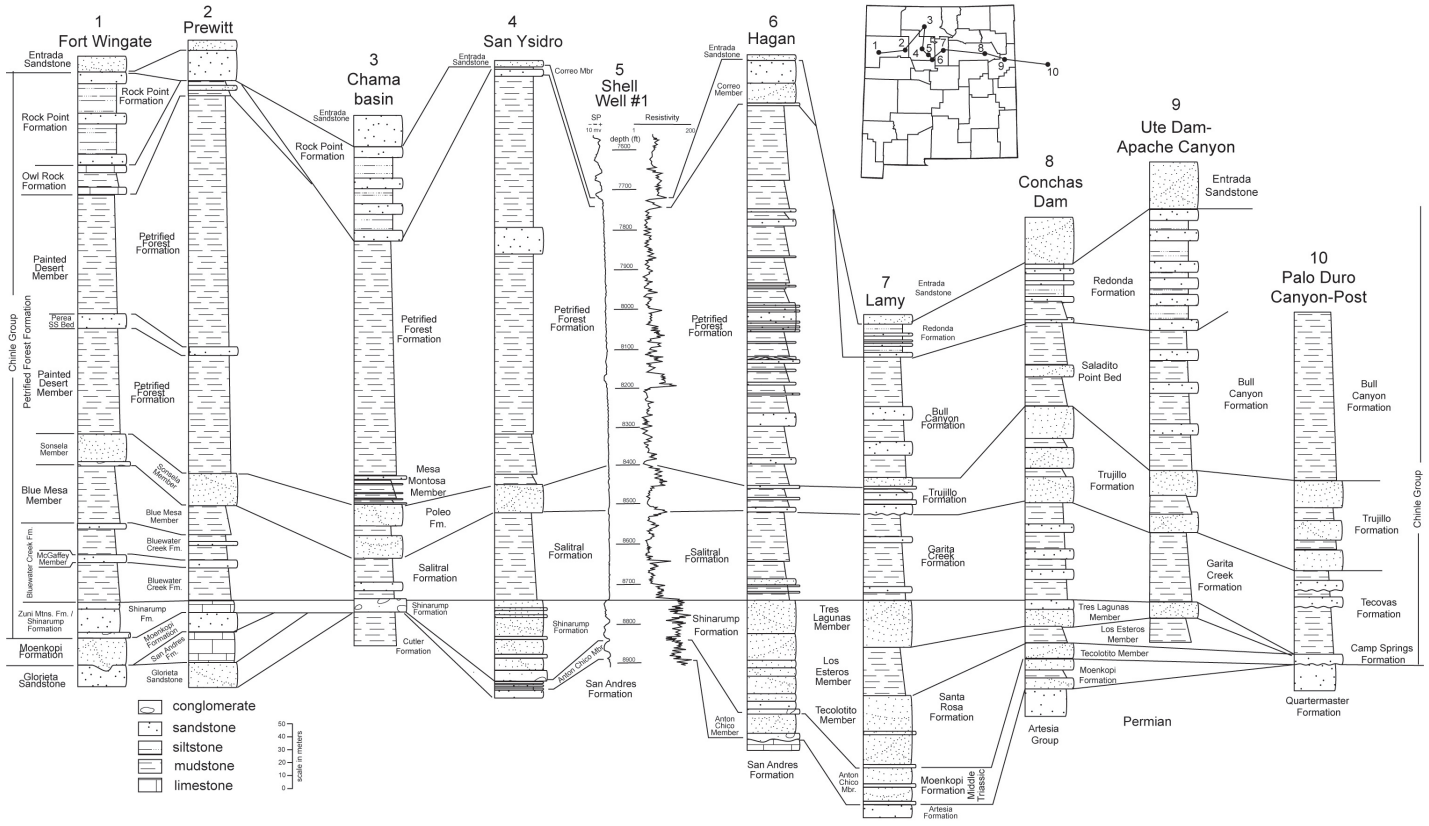

FIGURE 7. Correlation of the Chinle Group along a west-east transect across New Mexico into West Texas (modified from Lucas et al., 1999, 2001, 2003a).

west (Lucas et al., 1997; Heckert and Lucas, 2003) and the Bull Canyon Formation to the east (Lucas et al., 2001). This interval is moderately variable in thickness and becomes sandier to the east across New Mexico towards Ute Dam-Apache Canyon (Lucas et al., 2001). Farther east, the uppermost part of the Petrified Forest Formation and overlying Redonda Formation were eroded during the Neogene, so that the total thickness of the unit is not preserved in West Texas.

The Owl Rock Formation is present only to the west of the Chama Basin. The overlying Rock Point Formation is also not laterally continuous and varies substantially in thickness. It is apparently equivalent to the Redonda Formation to the east. The Rock Point Formation is not present at San Ysidro or in the Hagan basin, despite its thickness in the neighboring Chama Basin.

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