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TRIASSIC STRATIGRAPHY OF THE SOUTHEASTERN COLORADO PLATEAU, WEST-CENTRAL NEW MEXICO

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Abstract—Triassic strata are well exposed along the southeastern Colorado Plateau and in adjacent areas in west-central New Mexico (McKinley, Catron, Cibola and parts of Valencia and Socorro counties). The oldest Triassic strata are assigned to the Anton Chico Member of the Moenkopi Formation, which disconformably overlies Permian strata and is disconformably overlain by the Upper Triassic Chinle Group. The Moenkopi Formation in west-central New Mexico is as much as 68 m thick, and consists of mostly grayish-red and reddish-brown sandstone, mudstone siltstone and conglomerate. Overlying Triassic strata in west-central New Mexico are assigned to seven formations of the Chinle Group (in ascending order) – the Shinarump /Zuni Mountains formations, the Bluewater Creek/San Pedro Arroyo formations, the Petrified Forest Formation (including Blue Mesa, Sonsela and Painted Desert members), the Owl Rock Formation and the Rock Point Formation – and to the Wingate Sandstone. As much as 24 m of silica-pebble conglomerate/sandstone and pedogenically-modified and color-mottled siltstone, mudstone and sandstone of the Shinarump and Zuni Mountains formations, which are lateral equivalents, are at the base of the Chinle Group. The 50-60 m of Bluewater Creek Formation are dominated by red sandstones and mudstones and are laterally equivalent to the southeast to the color-mottled San Pedro Arroyo Formation. The Petrified Forest Formation is up to 441 m thick and is divided into the (ascending) Blue Mesa, Sonsela and Painted Desert members. The Blue Mesa Member is 21-45 m thick and mostly purplish and greenish bentonitic mudstone with calcrete nodules and a white tuffaceous sandstone locally present at the base. The Sonsela Member is 15-61 m thick and mostly yellowish-gray, cross-bedded sandstone and siliceous conglomerate with fossil logs. The Painted Desert Member is up to 325 m thick and is mostly reddish brown mudstone and siltstone. It includes some relatively thin, but laterally persistent sandstone units, the Perea and Correo beds. The Owl Rock Formation is up to 35 m thick and characterized by reddish siltstone and beds of white limestone. The Rock Point Formation is up to 70 m thick and consists of repetitively-bedded, reddish-brown sandstone and siltstone. The Wingate Sandstone is the stratigraphically-highest Triassic (?) unit in west-central New Mexico. The Moenkopi Formation is Anisian in age, whereas the Chinle Group ranges from middle Carnian to Rhaetian in age. The base of the Moenkopi Formation is a regional unconformity (Tr-0/Tr-2 unconformities), and the base of the Chinle Group is the regional Tr-3 unconformity. There are two within-Chinle regional unconformities, Tr-4 at the Sonsela base and Tr-5 (=J-0) at the Rock Point base. The Middle Jurassic Entrada Sandstone overlies Triassic strata across west-central New Mexico at the J-2 unconformity.

INTRODUCTION

Triassic strata in west-central New Mexico (Fig. 1) are assigned to the Moenkopi Formation and overlying Chinle Group (Fig. 2). Since Marcou (1858) first identified Triassic rocks in this part of the state (and in some other areas in New Mexico), a variety of lithostratigraphic relationships and names have been proposed. Triassic strata in west-central New Mexico are exposed over four outcrop belts: (1) the Triassic outcrop belt along the northern and western flanks of the Zuni Mountains, mostly between Gallup and Grants; (2) the Triassic outcrops located primarily on the Zuni Indian Reservation in western Cibola County and southwestern McKinley County: (3) Triassic outcrops in the upper drainage of Largo Creek and its tributaries, far western Catron County; and (4) Triassic strata that crop out in and around the Lucero uplift of eastern Cibola, western Valencia and northwestern Socorro counties (Fig. 1). Here, I review Triassic lithostratigraphy, chronostratigraphy and unconformities in these four outcrop belts.

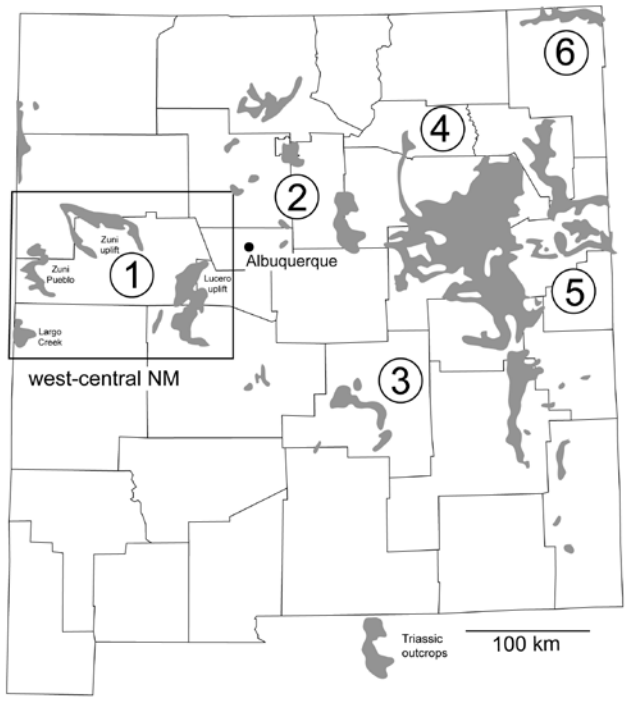

FIGURE 1. Distribution of Triassic outcrops in New Mexico showing location of west-central New Mexico outcrops. The numbers refer to the columns in Figure 12.

SOME HISTORY

Stewart et al. (1972a), Lucas and Hayden (1989) and Heckert and Lucas (2002, 2003) provided detailed reviews of the

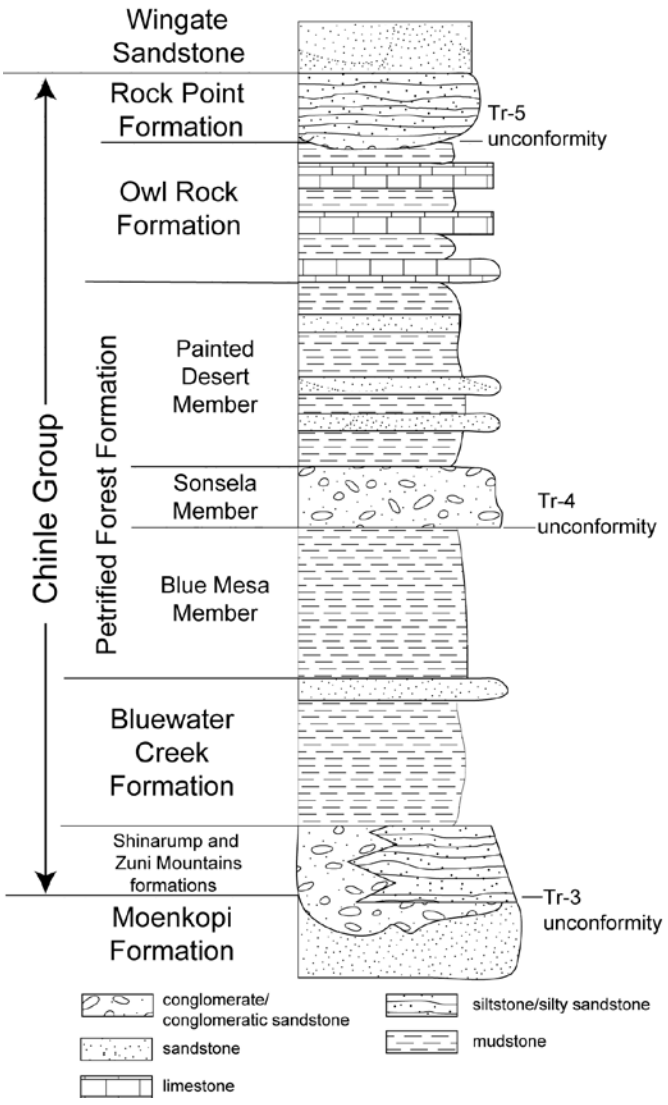

FIGURE 2. Generalized lithologic column of Triassic strata in west-central New Mexico.

development of the lithostratigraphic nomenclature of Triassic strata in west-central New Mexico, so I present only a brief review. Ten significant works represent turning points or syntheses of our understanding of Triassic stratigraphy in west-central New Mexico (Fig. 3).

Marcou (1858) identified Triassic strata in west-central New Mexico as "Trias" or "'New Red Sandstone." Newberry (1876) applied the informal name "Salt Group" to Permian and Triassic strata up to and including what is now termed the Sonsela Member, and he referred overlying Triassic and Jurassic strata to his "Marl Series." Working in the Zuni Mountains-Mount Taylor area, Dutton (1885) first applied formal stratigraphic names to Triassic strata in west-central New Mexico. He coined the name Wingate Sandstones for strata later assigned to the Entrada Sandstone and used Gilbert's (1875) term Shinarump Conglomerate for strata now termed Sonsela.

Darton (1910, p. 44-53) reviewed in detail the Triassic strata exposed throughout west-central New Mexico. Below Dutton's (1885) Wingate Sandstones, Darton equated Dutton's Lower Trias with Ward's (1901) Leroux Formation, at the base of which he identified the Shinarump Conglomerate. Below his Shinarump, Darton termed the Triassic strata Moencopie (?) formation (= Moencopie beds of Ward, 1901) above Pennsylvanian strata he considered correlative to the Aubrey Group of northern Arizona.

Darton (1928) followed the then current USGS practice in abandoning Ward's (l901) term Leroux in favor of Gregory's (1915) name Chinle. However, Darton (1910, 1928) erred in correlating what is now known to be the Sonsela Member in west-central New Mexico with the Shinarump Conglomerate in Arizona. Consequently, he assigned underlying Upper Triassic strata to the Lower-Middle Triassic Moenkopi Formation.

Bates (1942) first recommended abandoning Darton's use of Moenkopi in west-central New Mexico. Thus, when Kelley and Wood (1946) mapped a Triassic stratigraphy specific to the Lucero uplift, they did not assign any strata to the Moenkopi (although some later workers did, e.g., Momper, 1957). They identified the lower, grayish-red, sand-dominated portion of the Triassic section as Shinarump Conglomerate overlain by "shale"-dominated Chinle Formation capped by a prominent sandstone at Mesa Gigante that they named the Correo Sandstone Member of the Chinle (Fig. 3).

Smith (1954, 1957), working in the Zuni uplift, followed McKee (1954), who argued that both the Moenkopi and the Shinarump are not present in west-central New Mexico. Smith thus used an informal subdivision of the Triassic strata in this area, all of which he assigned to the Chinle Formation (Fig. 3). Smith's lower and upper Chinle members were mudrock dominated and split by the sandstone-dominated middle member. Smith also assigned to the Correo Sandstone Member the upper Chinle sandstones west of Mesa Gigante that were stratigraphically much lower in the Chinle-mudrock section.

Cooley's (1957) detailed study of Triassic stratigraphy in the drainage of the Little Colorado River was published by Akers et al. (1958), Cooley (1958, 1959a, b) and Cooley et al. (1969). At the base of the Triassic section, Cooley tentatively identified "upper Moenkopi (?)" above Permian strata. At the base of the overlying Chinle Formation, he identified scattered channel-type deposits as Shinarump, and he named a lower member the Mesa Redondo Member. A "lower red member" rested on the Shinarump and was capped by the thick, mudrock-dominated Petrified Forest Member split by the Sonsela Sandstone Bed. According to Cooley (1957), the youngest Triassic rock-stratigraphic unit in west-central New Mexico, the Owl Rock Member of the Chinle Formation, only extends as far east as Thoreau. He also noted that the underlying upper Petrified Forest Member contains a number of laterally persistent sandstone beds, including the Correo Sandstone Bed.

Stewart et al. (1972b, c) followed the nomenclature of Cooley with few significant changes. The only addition was their recognition of the "mottled strata" at the base of the Chinle in west-central New Mexico. Lucas and Hayden (1989) named the Bluewater Creek Member but otherwise used the same lithostratigraphy. Subsequent extensive stratigraphic work by Heckert (1997) and by the author in collaboration with Heckert, Ander-

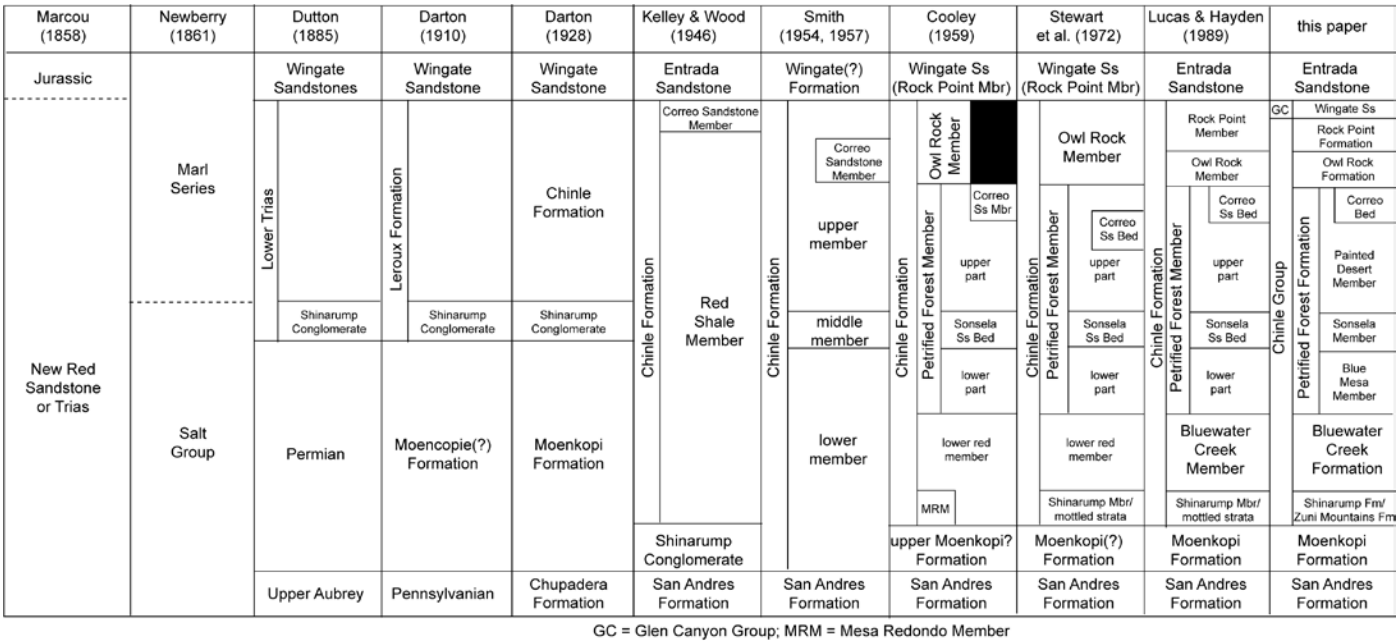

FIGURE 3. Historical development of lithostratigraphic nomenclature of Triassic strata in west-central New Mexico.

son, Hunt and Tanner produced the lithostratigraphy advocated here and briefly summarized below (Lucas, 1995, 2004).

MOENKOPI FORMATION

The oldest Triassic strata in west-central New Mexico are assigned to the Anton Chico Member of the Moenkopi Formation of Lucas and Hunt (1987). The Moenkopi Formation is as much as 25 m thick and consists primarily of sandstone (lithic arenites and lithic wackes), siltstone and minor conglomerate and mudstone (e.g., Lucas and Hayden, 1989). Moenkopi strata are mostly grayish red, but some beds are reddish purple, pale green or orange brown. Sandstone beds are trough cross-bedded or laminar. The conglomerate clasts are mostly intraformational calcrete and mudrock rip ups, but locally chert and limestone clasts are present, likely derived from the underlying Permian San Andres Formation.

In west-central New Mexico, the Middle Triassic (see below) Anton Chico Member of the Moenkopi Formation rests with profound unconformity on the lower Permian San Andres Formation or, locally, on the lower Permian Glorieta Sandstone. One striking aspect of this unconformity is paleotopography of the Moenkopi-San Andres contact that includes a karst topography developed in the top of the San Andres Formation in the Zuni uplift (Fig. 4). The Moenkopi Formation in west-central New Mexico is disconformably overlain by the Shinarump or Zuni Mountains formations at the base of the Upper Triassic Chinle Group (Figs. 5, 6).

CHINLE GROUP

Lucas (1993) raised the Chinle to group rank, although some workers continue to recognize it as a formation (e.g., Cather et al., 2013). I recognize seven formations of the Chinle Group in west-central New Mexico (in ascending order): Shinarump/Zuni Mountains formations, Bluewater Creek/San Pedro Arroyo formations, Petrified Forest Formation, Owl Rock Formation and Rock Point Formation (Figs. 2, 3, 6).

Shinarump and Zuni Mountains formations

As just noted, the base of the Chinle Group is a profound disconformity on the Moenkopi Formation across west-central New Mexico. This disconformity is locally marked by beds of

FIGURE 4. Paleokarst feature developed in the top of the Permian San Andres Formation with collapse debris of Moenkopi Formation in Sixmile Canyon in the northern Zuni Mountains (NE1/4 T14N, R16W, McKinley County).

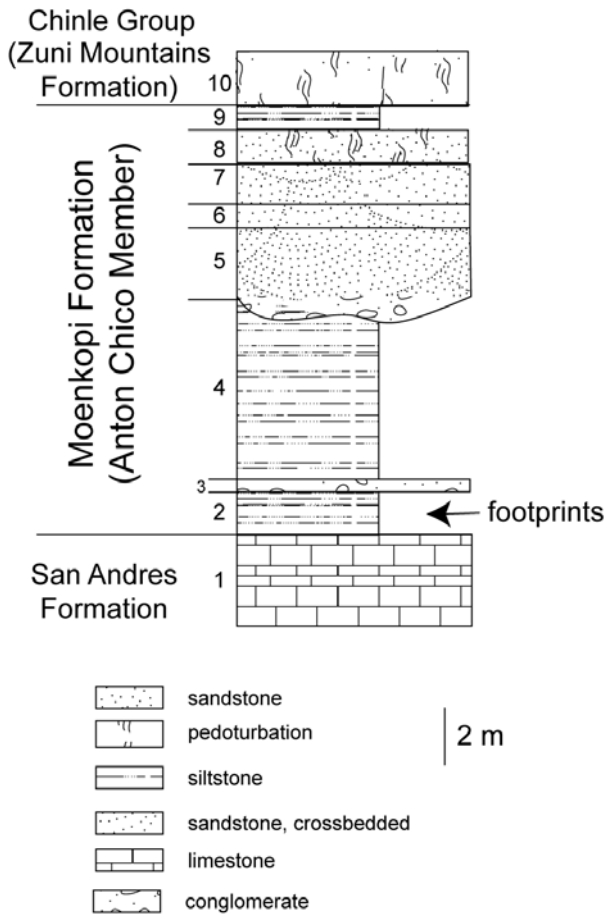

FIGURE 5. Characteristic stratigraphic section of Moenkopi Formation in west-central New Mexico at Bluewater Creek in the northern Zuni Mountains (NE 1/4 T12N, R12W, Cibola County).

silica-pebble conglomerate and quartzose sandstone that represent some of the easternmost outcrops of the Shinarump Formation. Laterally equivalent are pedogenically modified siltstones, mudstones and sandstones that Stewart et al. (1972b) termed the "mottled strata" and that Heckert and Lucas (2003) named the Zuni Mountains Formation.

The Zuni Mountains Formation consists of pedoturbated sandstone and siltstone that are color-mottled shades of purple, red, yellow, white, blue and gray. The most extensive exposures of the Zuni Mountains Formation in west-central New Mexico are south of Fort Wingate (Lucas and Hayden, 1989), where about 25 m of Zuni Mountains strata are exposed between the Moenkopi Formation and Bluewater Creek Formation of the Chinle, mapped by Anderson et al. (2003). These strata host abundant vertical, tubular sandstone casts (Fig. 7) originally interpreted as lungfish burrows (Dubiel et al., 1987; McAllister, 1988), later as crayfish burrows (Hasiotis and Dubiel, 1993; Hasiotis et al., 1993), but best identified as rhizoliths (Lucas and Hayden, 1989; Tanner and Lucas, 2007).

Up to 7 m thick, the Shinarump Formation in west-central New Mexico is generally too thin and laterally discontinuous to be mappable at a scale of 1:24,000. Shinarump strata are yellowish gray to light brown, trough cross-bedded conglomeratic sandstone, conglomerate and quartzose sandstone. Conglomerate clasts are almost all siliceous (chert and quartzite), and pieces of silicified wood up to 0.5 m in diameter are locally present. The name Agua Zarca Member (or Formation) has been applied to similar deposits in north-central New Mexico (Cather et al., 2013).

Bluewater Creek Formation

Diverse workers long identified the presence of a lower, red, sandy interval of the Chinle Formation between the Shinarump Member/mottled strata and the lower part of the Petrified Forest Member on the southeastern Colorado Plateau (Cooley, 1957, 1959a; Repenning et al., 1969; Stewart et al., 1972b). Lucas and Hayden (1989) named this interval in west-central New Mexico the Bluewater Creek Member of the Chinle Formation, and Lucas (1993) raised it to formation rank.

The Bluewater Creek Formation rests conformably on the Zuni Mountains Formation and is conformably overlain by the Blue Mesa Member of the Petrified Forest Formation. In west-central New Mexico, the Bluewater Creek Formation is consistently 50-60 m thick and can be divided into three lithofacies (see Heckert and Lucas, 2002, 2003): (1) a relatively thin interval (5-10 m thick) of greenish gray bentonitic mudstone and carbonaceous shale that is only locally present at the base of the member (Fig. 6), including the "Ciniza Lake Beds" of Ash (1978); (2) beds of mudstone and minor siltstone, some with horizons of calcrete nodules, that are brightly variegated reddish brown, bluish gray and grayish purple, that form colorful badlands and are the bulk of the formation's outcrops (Fig. 8); and (3) sandstone beds, generally 4-6 m thick but locally up to 20 m thick, that are fine- to medium-grained micaceous sublitharenite and litharenite and are ripple-laminar, laminar or tabular bedded.

Locally, the sandstone beds have conglomerate lenses of calcrete-pebble rip ups. A persistent and relatively thick sandstone interval in the upper part of the Bluewater Creek Formation is the McGaffey Member of Anderson and Lucas (1993). The Bluewater Creek Formation is present throughout the Zuni uplift and present in the subsurface in the Zuni Pueblo area where it interfingers with Cooley's (1958) Mesa Redondo Member (Repenning et al., 1969). In the Lucero uplift, the Bluewater Creek Formation grades southeastward into the San Pedro Arroyo Formation (Lucas and Heckert, 1994).

Petrified Forest Formation

The majority of the Chinle Group in west-central New Mexico is assigned to the Petrified Forest Formation, which is up to 441 m thick. The threefold division of the Petrified Forest Formation recognized in east-central Arizona can be identified in west-central New Mexico (Lucas, 1993; Heckert and Lucas, 2002, 2003). Thus, the lower part of the Petrified Forest Formation is the Blue Mesa Member (mostly bluish and purple, bentonitic mudstones) overlain by the Sonsela Member (mostly sandstone and conglomerate) below the reddish, mudstone- and siltstone-dominated Painted Desert Member (Figs. 2, 6).

The most extensive outcrops of the Petrified Forest Formation in west-central New Mexico are along the northern dip slope of the Zuni uplift.

Blue Mesa Member

The Blue Mesa Member in west-central New Mexico forms a slope between the Bluewater Creek Formation and overlying Sonsela Member (Fig. 8). It is 21-45 m thick and mostly purplish and greenish, highly bentonitic mudstone with numerous calcrete nodules. The base of the member at most outcrops in west-central New Mexico is a white tuffaceous sandstone (Figs. 6, 8). The Blue Mesa Member thins from west to east due to erosion at the base of the overlying Sonsela Member (Heckert and Lucas, 1996; Fig. 6). Indeed, the Blue Mesa Member is absent in the Lucero uplift where the Sonsela rests directly on the Bluewater Creek Formation and laterally equivalent strata of the San Pedro Arroyo Formation (Lucas and Heckert, 1994).

Sonsela Member

The Sonsela Member in west-central New Mexico is a cuesta- and cliff-forming unit of two sandstone intervals, each 8-12 m thick, split by a mudrock interval that is 4-10 m thick (Figs. 6, 9). The Sonsela forms the prominent hogback between Fort Wingate and I–40 and the top of the northern dip-slope of the Zuni Mountains from Thoreau to Prewitt just south of I–40. The thickness of the Sonsela Member in west-central New Mexico ranges from 15-61 m (Cooley, 1957, 1959a; Repenning et al., 1969; Heckert and Lucas, 2002, 2003).

The sandstone intervals of the Sonsela Member consist of light-gray to yellowish-brown, fine-grained to conglomeratic, cross-bedded sandstone (sublitharenites and subarkoses) with thin lenses of bluish-gray to grayish-purple mudstone and siltstone. Conglomeratic sandstone and some beds of conglomerate are usually present, and clasts are siliceous – mostly chert and quartzite – but include some mudstone and calcrete rip ups. Particularly characteristic of the Sonsela Member in west-central New Mexico are silicified fossil logs up to 1 m in diameter.

Painted Desert Member

The Painted Desert Member is poorly exposed in west-central New Mexico. The most extensive outcrops are those near Thoreau in the northern half of Tl4N, R12W, R13W and R14W. As much as 335 m thick near Thoreau (Repenning et al., 1969), the Painted Desert Member is mostly variegated brownish-red, grayish-red, pale reddish-brown and pale reddish-purple mudstone, siltstone and sandy siltstone beds. Sandstone beds in this thick, mudrock-dominated unit are micaceous and cross-bedded. A few thin conglomerate beds have clasts that are mudstone and calcrete-pebble rip ups.

Near Thoreau, there are several prominent sandstone beds in the Petrified Forest Member. These beds are composed of pale-red and grayish-red, very fine- to medium-grained, planar cross-bedded sandstone. Cooley (1957) applied formal names (Chambers, Taaiylone, Zuni River and Perea) to beds like these in eastern Arizona and west-central New Mexico, and Lucas et al. (1997a) formalized the name Perea Bed for a sandstone unit low in the Painted Desert Member in the Fort Wingate-Perea area (Fig. 10).

The Correo Bed of Kelley and Wood (1949) is a prominent sandstone interval in the upper part of the Painted Desert Member named for outcrops at Mesa Gigante in the northern Lucero uplift (Stewart et al., 1972b; Lucas et al., 1987, 1997b; Lucas, 1993). It has been recognized as far east as the Hagan basin of Sandoval County (Lucas, 1991a), in the southeastern San Juan Basin (Lucas and Heckert, 1996), and possibly as far west as R12W just east of Thoreau (Lucas and Hayden, 1989).

San Pedro Arroyo Formation

Along the southern and eastern edges of the Lucero uplift most of the strata of the lower part of the Chinle Group belong to the San Pedro Arroyo Formation of Lucas (1991b; also see Spielmann and Lucas, 2009). The San Pedro Arroyo Formation in the Lucero uplift is as much as 90 m thick and consists of grayish-red-purple mudstones with minor sandstone, conglomerate, siltstone and calcrete laterally equivalent to muddier strata of the Bluewater Creek Formation to the north and west (Lucas and Heckert, 1994).

At Carrizo Spring in the eastern Lucero uplift, the lower part of the San Pedro Arroyo Formation contains a limestone interval that is the Ojo Huelos Member of Lucas (1991a). This limestone is micrite and pisolitic rudstone that is color-mottled medium gray, grayish-orange, pale-reddish brown and dusky purple, and some beds contain chert or are silicified (Lucas et al., 2004; Tanner and Lucas, 2012). It represents pedogenic calcrete and palustrine deposits (Tanner and Lucas, 2012).

OWL ROCK FORMATION

The Owl Rock Formation conformably overlies the Painted Desert Member of the Petrified Forest Formation and is present, but very poorly exposed, in the Zuni Pueblo area north of the Zuni River (Cooley, 1957, 1959a; Repenning et al., 1969). The best exposures of the Owl Rock Formation in west-central New Mexico are on the northern dip slope of the Zuni Mountains between Red Rocks north of Fort Wingate (NE ¼, Tl5N, R 17W) and in the Mount Powell-Thoreau area (NE ¼, Tl4N, Rl4W, and N ½, Tl4N, Rl3W).

In west-central New Mexico, the Owl Rock Formation is as much as 35 m thick and contains laterally persistent beds of pale-red and pale-reddish-brown, calcareous siltstone, thin-bedded sandy siltstone and light-greenish-gray limestone and nodular limestone. The limestone beds (Fig. 11) are characteristic of the unit. They are up to 4 m thick, well indurated and have rhizoliths and other evidence of pedogenesis. They are pedogenic calcrete and palustrine-lacustrine limestones (Tanner, 2000, 2003). Across west-central New Mexico, the Owl Rock Formation is overlain disconformably by the Entrada Sandstone, the Rock Point Formation of the Chinle Group, or the Wingate Sandstone (Stewart et al., 1972b; Maxwell, 1982, 1988a, b; Lucas and Heckert, 1996, 2003).

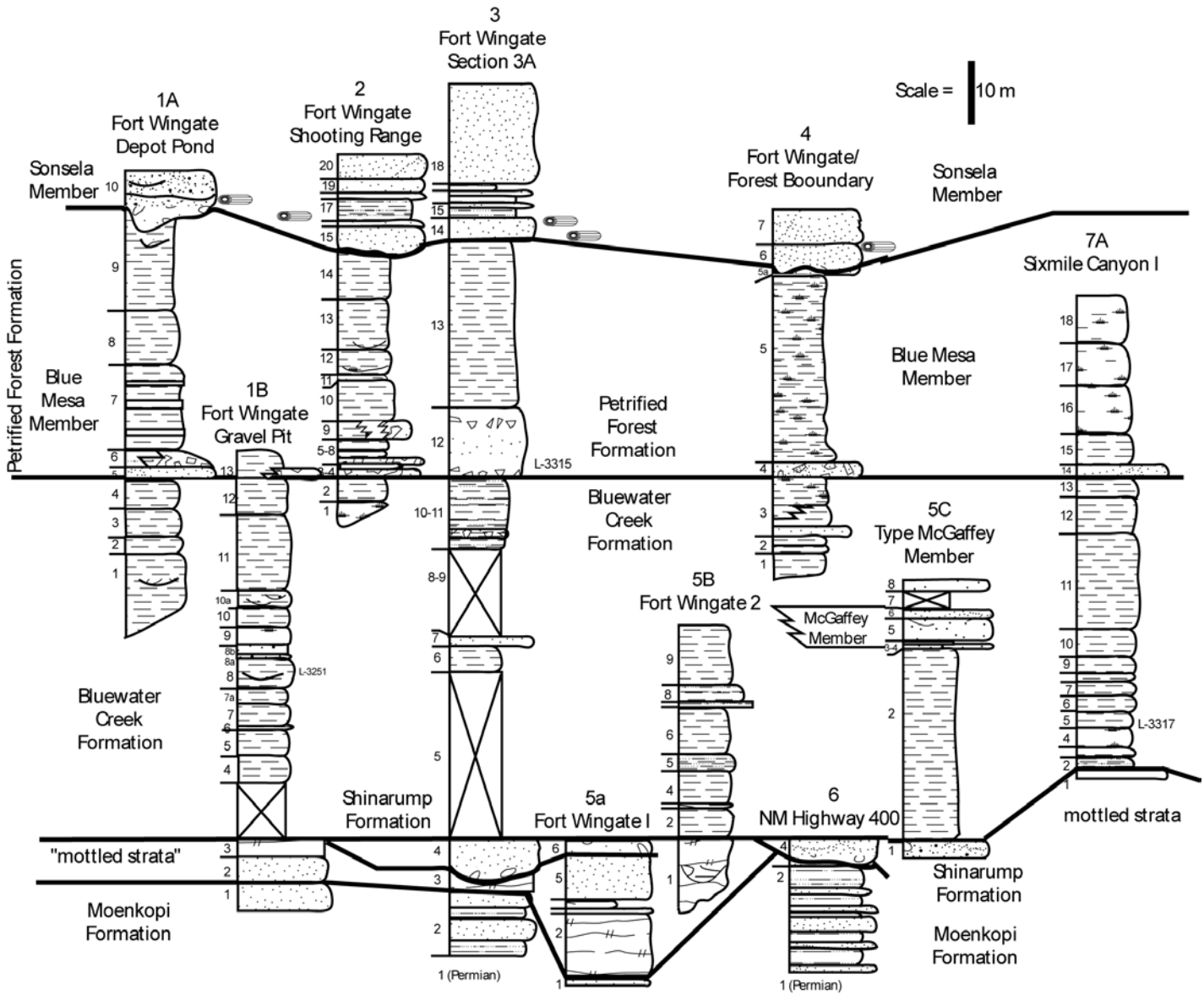

FIGURE 6. Stratigraphy of lower part of Chinle Group in the Zuni Mountains (after Heckert and Lucas, 2002). See Heckert and Lucas (2002) for precise locations of stratigraphic sections.

Rock Point Formation

Across west-central New Mexico, the Rock Point Formation is repetitively bedded, reddish-brown beds of sandy siltstone and silty sandstone. The siltstone beds are massive, whereas the sandstone beds are laminar, ripple laminar or massive. The sandstones are micaceous quartzarenite. In west-central New Mexico, the Rock Point Formation is best exposed in the Zuni Pueblo area in the Zuni Buttes-Dowa Yalanne area (T10N, R19W and R20W). Here, it is 37 m or more of pale- to moderate-reddish brown, intercalated beds of fine-grained sandstone, sandy siltstone and silty mudstone that is flaggy to slabby bedded. The Rock Point Formation is not present to the south in Catron County, where strata of the Painted Desert Member of the Petrified Forest Formation are at the top of the Triassic section. However, it is present in the Zuni uplift, where it is disconformably overlain by the Wingate Sandstone (to the west) and the Dewey Bridge Member (to the east) of the Entrada Sandstone (e.g., Maxwell, 1982).

Uppermost Chinle strata in the Lucero uplift have long been assigned to the Rock Point Formation. Here, Maxwell (1988a, b) identified the Rock Point Member as isolated outcrops of as much as 50 m of pale-red, moderate-red and reddish-purple, shaley siltstone and mudstone with a few sandstone beds. The

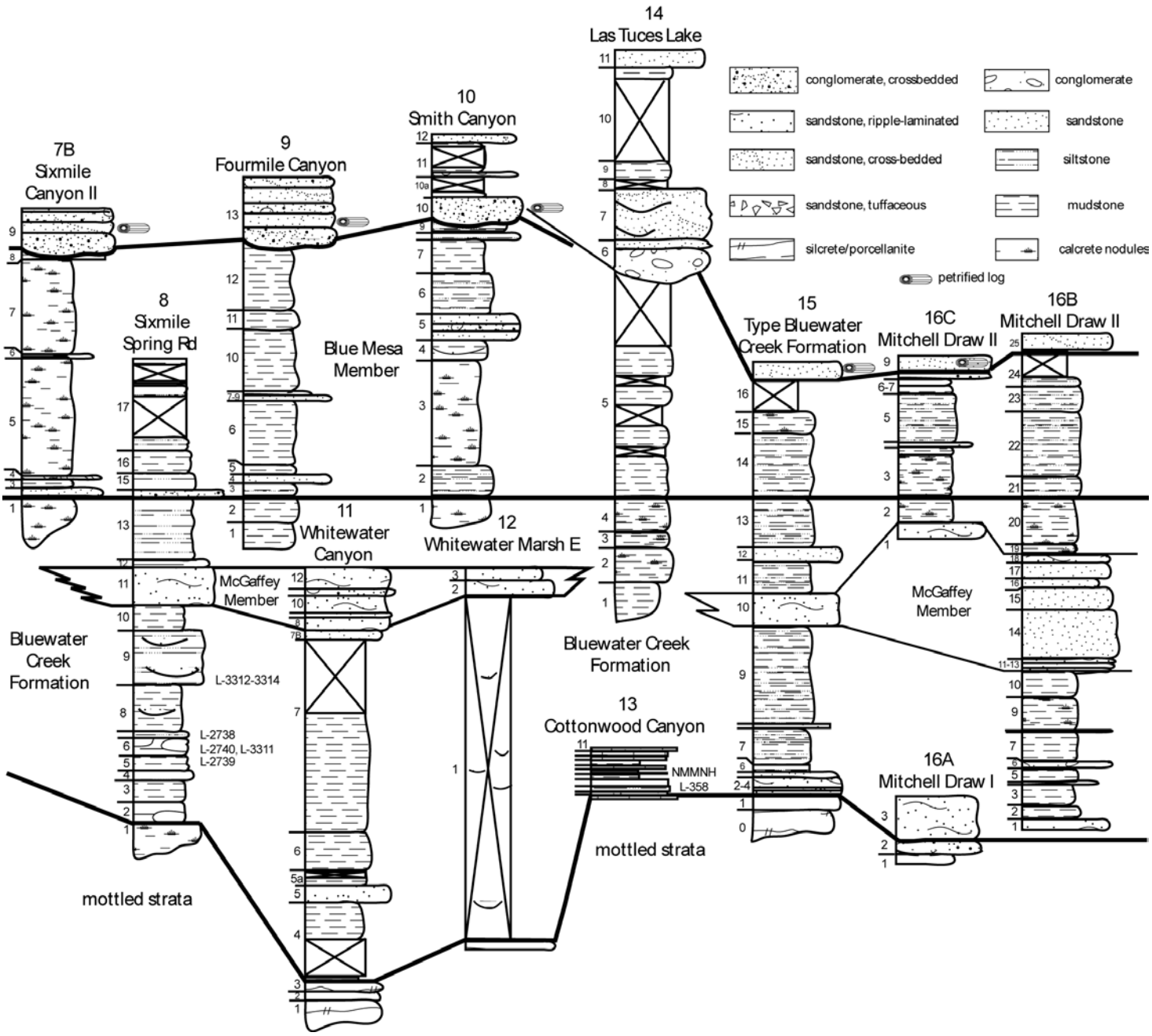

FIGURE 6. Continued.

maximum Rock Point Formation thickness is 70 m in the Petaca Pinta area in the SW1/4, T6N, R6W, and the SE1/4, T6N, R7W (Lucas and Heckert, 1994).

WINGATE SANDSTONE

The unit called the Wingate Sandstone in west-central New Mexico has a long and complicated nomenclatural history reviewed in detail by Lucas and Heckert (2003). I accept the conclusion that this unit is correlative to the unit Harshbarger et al. (1957) named the Lukachukai Member of the Wingate Sandstone in the Four Corners region, which is now the Wingate Sandstone of regional usage. The Wingate Sandstone in the Four Corners region encompasses the Triassic-Jurassic boundary (e.g., Lucas and Tanner, 2007), so it is possible the strata of the Wingate Sandstone in west-central New Mexico are of Early Jurassic age.

CHRONOSTRATIGRAPHY AND REGIONAL UNCONFORMITIES

The ages of Triassic stratigraphic units in west-central New Mexico are based primarily on biostratigraphy supplemented by limited magnetostratigraphic data and radioisotopic ages from across the Triassic outcrop belts in the western United States (see Lucas, 1993, 1997, 2013, 2018; Lucas et al., 2012;

FIGURE 7. Outcrop of Zuni Mountains Formation at Fort Wingate, showing color mottling due to pedogenesis and prominent, vertical, tubular rhizoliths (NE ¼ T14N, R16W, McKinley County).

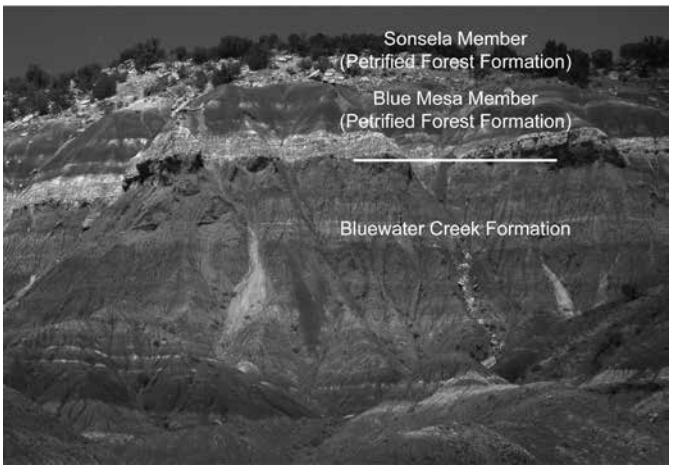

FIGURE 8. Part of the type section of the Bluewater Creek Formation at Bluewater Creek (NE ¼ T12N, R12W, McKinley County).

FIGURE 9. Characteristic outcrop of Sonsela Member of the Petrified Forest Formation along Sixmile Canyon in the northern Zuni Mountains (NE ¼ T14N, R16W, McKinley County). Note overturned cross-beds in the middle of the photograph.

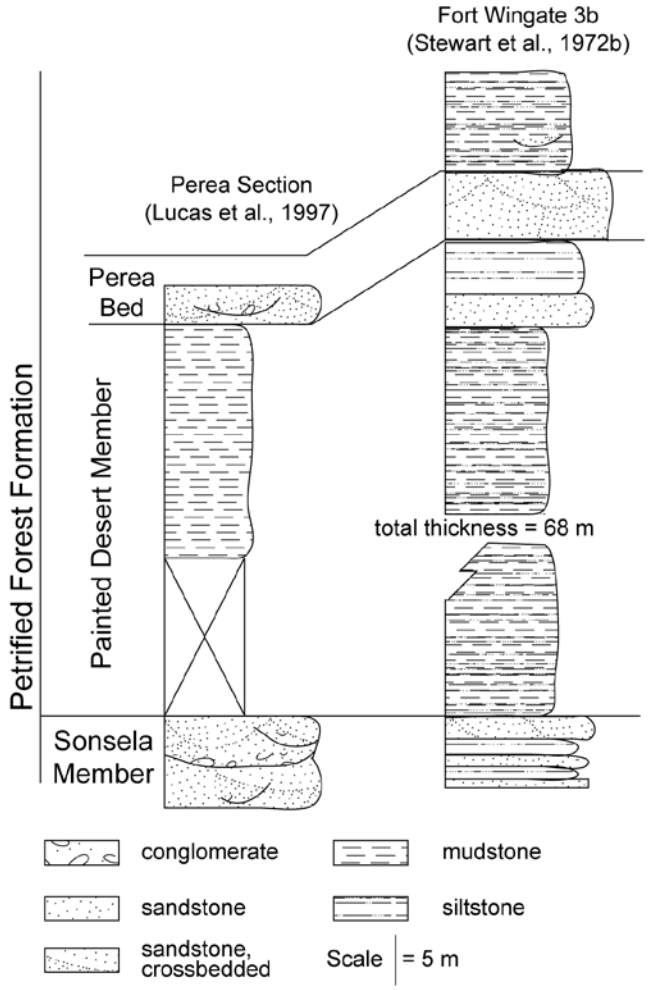

FIGURE 10. Some representative stratigraphic sections of part of the Painted Desert Member of the Petrified Forest Formation near Fort Wingate.

FIGURE 11. Characteristic outcrop of part of Owl Rock Formation, on the frontage road of I–40 near Red Rocks (NE ¼ T15N, R17W, McKinley County). Note prominent, thick limestone interval in lower part of outcrop. Measuring stick is 1.5 m long.

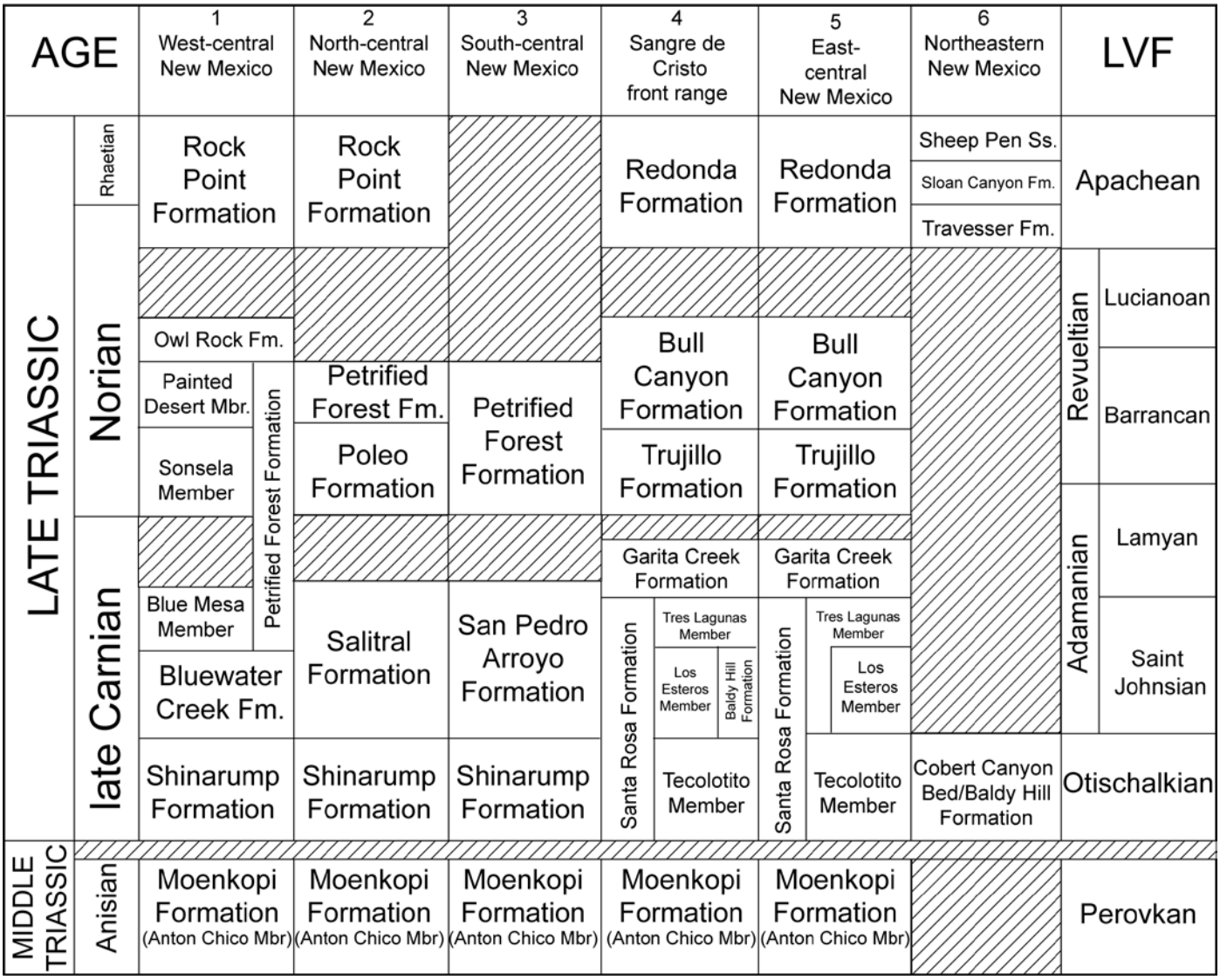

FIGURE 12. Correlation of Triassic stratigraphic units in New Mexico (after Lucas, 2004). The column numbers refer to numbers on the map in Figure 1. LVF = land-vertebrate faunachrons.

Heckert and Lucas, 2015; and Lucas and Tanner, 2018, for summaries). Biostratigraphy and magnetostratigraphy indicate that the Anton Chico Member of the Moenkopi Formation is of early Anisian (Bithynian) age (e.g., Lucas and Schoch, 2002). Chinle Group strata are of Late Triassic age (middle Carnian to Rhaetian) based on all available age data (i.e., biostratigraphy, some radioisotopic ages and magnetostratigraphy).

As noted above, the base of the Moenkopi Formation is an unconformity, a compounding of the Tr-0 through Tr-2 unconformities of Pipiringos and O'Sullivan (1978), a hiatus of about 30 Ma. The base of the Chinle Group is the Tr-3 regional unconformity of Pipiringos and O'Sullivan (1978), a hiatus of at least 15 Ma. The stratigraphic correlation and chronology of the Chinle Group advocated here (Fig. 12) and elsewhere identify two intra-Chinle Group unconformities and thus delineate three depositional sequences (Fig. 2). Lucas (1993) labeled these two unconformities Tr-4 and Tr-5 (= J-0), following the scheme of Pipiringos and O'Sullivan (1978).

Evidence for the widespread intra-Chinle Group unconformities is fourfold: (1) Correlative rocks immediately above each unconformity overlie rocks of different ages in different areas. This probably reflects differential erosion associated with each unconformity; (2) There is a major lithologic change associated with each unconformity. Rocks of the upper part of the Shinarump-Blue Mesa sequence are smectitic mudstones, siltstones and pedogenic silcretes/calcretes overlain by sandstones and conglomerates at the base of the Sonsela-Owl Rock sequence. Smectitic mudstones and pisolitic calcretes of the upper part of the Sonsela-Owl Rock sequence are directly overlain by non-smectitic siltstones and mudstones and fine-grained, laterally persistent sandstones of the Rock Point sequence; (3) At the Tr-4 unconformity, channeling into and reworking of underlying sediment is evident in many areas (e.g., Heckert and Lucas, 1996). At the Tr-5 unconformity, there is evidence of extensive subaerial weathering (pedogenesis) of sediments immediately beneath

the unconformity; and (4) Each unconformity corresponds to a significant reorganization of the biota. Few genera of tetrapods cross an unconformity, so that many tetrapod taxa are unique to each of the three depositional sequences (Lucas, 2018). This is also generally true of palynomorphs, megafossil plants, ostracods and fishes. A temporal hiatus associated with each unconformity best explains this pattern. The Middle Jurassic Entrada Sandstone rests with unconformity (compound J1/J2 unconformity) on Triassic strata across west-central New Mexico.

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