Triassic stratigraphy, paleontology and correlation, south-central New Mexico

Spencer G. Lucas

1991, pp. 243-259. https://doi.org/10.56577/FFC-42.243

in:

Geology of the Sierra Blanca, Sacramento, and Capitan Ranges, New Mexico, Barker, J. M.; Kues, B. S.; Austin, G. S.; Lucas, S. G.; [eds.], New Mexico Geological Society 42 nd Annual Fall Field Conference Guidebook, 361 p. https://doi.org/10.56577/FFC-42

This page is intentionally left blank to maintain order of facing pages.

TRIASSIC STRATIGRAPHY, PALEONTOLOGY AND CORRELATION, SOUTH-CENTRAL NEW MEXICO

SPENCER G. LUCAS
New Mexico Museum of Natural History, 1801 Mountain Road NW, Albuquerque New Mexico 87104

Abstract—Triassic strata in south-central New Mexico (Valencia, Socorro and Lincoln Counties) pertain to the Moenkopi, Shinarump, Santa Rosa and San Pedro Arroyo Formations. The Moenkopi Formation is as much as 102 m thick, is dominated by grayish red, trough-crossbedded litharenite and rests disconformably on Permian strata of the Artesia Formation. As much as 5 m of pedogenically modified, color-mottled sandstone, siltstone and conglomerate above Moenkopi strata in parts of south-central New Mexico are identified informally as the mottled strata. The Shinarump Formation (Valencia and Socorro Counties) and Santa Rosa Formation (Lincoln County) of the Chinle Group overlie the Moenkopi Formation or mottled strata. The Shinarump is as much as 6 m of trough-crossbedded, silica-pebble conglomerate, whereas the Santa Rosa is 13–26 m of silica-pebble conglomerate and micaceous subarkose. The mudstone-dominated Upper Triassic strata in south-central New Mexico above the Shinarump and Santa Rosa are here named the San Pedro Arroyo Formation, which includes as much as 123 m of variegated, bentonitic mudstone and minor conglomerate, sandstone, siltstone and limestone. A distinctive, limestone-dominated interval in the lower part of the San Pedro Arroyo Formation is here named the Ojo Huelos Member. Sparse paleontological evidence supports an Anisian age for the Moenkopi Formation in south-central New Mexico and indicates a late Carnian age for the lower part of the San Pedro Arroyo Formation (including the Ojo Huelos Member). The upper part of the San Pedro Arroyo Formation is Late Triassic, but a more precise age cannot be determined from available data. Fossils, lithology and stratigraphic sequence allow correlation of the Triassic strata in south-central New Mexico with Triassic strata elsewhere in the state.

INTRODUCTION

Triassic strata exposed in south-central New Mexico (Valencia, Socorro and Lincoln Counties; Fig. 1) have long been identified as Chinle, Santa Rosa and/or Dockum Formation (Group) and have only been studied intermittently. As a result, little is known of the lithologies, stratigraphic sequence and paleontology of these rocks. Their correlation with better-studied Triassic strata on the Colorado Plateau to the northwest and on the southern High Plains to the north and the east thus remains uncertain. Here, I re-evaluate Triassic strata and fossils from south-central New Mexico and thereby establish their correlation. In this article, NMMNH refers to the New Mexico Museum of Natural History, Albuquerque.

PREVIOUS STUDIES

Relatively little effort has been spent studying Triassic rocks in south-central New Mexico. Instead, published data are almost exclusively in geologic maps or reports on regional geology. And, although Case (1916) first recognized Late Triassic fossils from red beds in Socorro County, until recently no further paleontological studies have been published.

Along the eastern edge of the Colorado Plateau in western Valencia County, Triassic strata have long been referred to simply as Chinle Formation (Kelley and Wood, 1946; Callender and Zilinski, 1976). In eastern Valencia County, and in Socorro County, they have usually been termed Chinle Formation (Shale) above Santa Rosa Sandstone and included in the Dockum Group (e.g., Wilpolt and Wanek, 1951; Fagrelius, 1982). However, the terms Dockum Formation (e.g., Myers et al., 1986) or Dockum Group (e.g., Bates et al., 1947), without attempt at subdivision, have also been applied.

Darton (1928, p. 91–92) provided the first cogent observations on Triassic rocks in Lincoln County, New Mexico:

> Red shale and sandstone overlying the Chupadera formation along the east side of the north end of the Tularosa Valley are probably in large part of Triassic age and presumably represent the Dockum group, but locally they may possibly include some Permian beds at the base and Morrison beds above. They crop out extensively about Ancho and in a zone extending southward and passing under the Malpais, southwest of Coyote. They reappear again west of Oscuro, and there are outcrops at intervals to a point southeast of Three Rivers. Similar strata also appear under the Dakota(?) sandstone on the east side of the basin near Capitan and Fort Stanton. They may include in their upper part a representative of the Morrison formation, for some of the material resembles the Morrison of northern New Mexico. This is well shown at the fire-clay mine 1 3/4 miles east of Ancho.

After these initial observations, a Triassic stratigraphic nomenclature for Lincoln County essentially identical to that used in Valencia and Socorro Counties arose (Fig. 2). Thus, a lower, sandstone-dominated portion of the Triassic was usually identified as Santa Rosa Sandstone, overlain by mudstone-dominated Chinle Formation, both included in the Dockum Group (e.g., Allen and Jones, 1951; Rawson, 1957; Budding, 1964; Smith, 1964; Weber, 1964; Haines, 1968; Ryberg, 1968; Kelley, 1971, 1972a, b). Only recently has work been undertaken to refine our understanding of Triassic stratigraphy and paleontology in south-central New Mexico (Hunt and Lucas, 1988; Lucas and Hayden, 1988; Lucas et al., 1988; Hayden et al., 1990). The results of this work are presented here and they modify significantly the nomenclature of Triassic strata in south-central New Mexico (Fig. 2).

STRATIGRAPHY

Triassic strata in south-central New Mexico pertain to the Moenkopi Formation (Anton Chico Member) of Middle Triassic age and the Shinarump, Santa Rosa and San Pedro Arroyo Formations (all in the Chinle Group: Lucas, 1991b) of Late Triassic age. The San Pedro Arroyo Formation is a new lithostratigraphic unit defined here which also includes a new member-level unit in Valencia and Socorro Counties, the Ojo Huelos Member, also defined here.

Moenkopi Formation

Strata of the Anton Chico Member of the Moenkopi Formation in south-central New Mexico are as much as 102 m thick and rest disconformably on the Permian (Guadalupian) San Andres or Artesia Formations (the term Bernal Formation should be abandoned and replaced by Artesia Formation in south-central New Mexico: Lucas and Hayden, 1991). A paleoweathering profile, the "mottled strata," are often at the top of the Moenkopi Formation in south-central New Mexico, and these strata, or nonweathered Moenkopi strata, are directly overlain by the Upper Triassic Shinarump, Santa Rosa or San Pedro Arroyo Formations or the Lower Cretaceous Mesa Rica Sandstone of the Dakota Group. This unconformable contact is the Tr-3 unconformity of Pipiringos and O'Sullivan (1978).

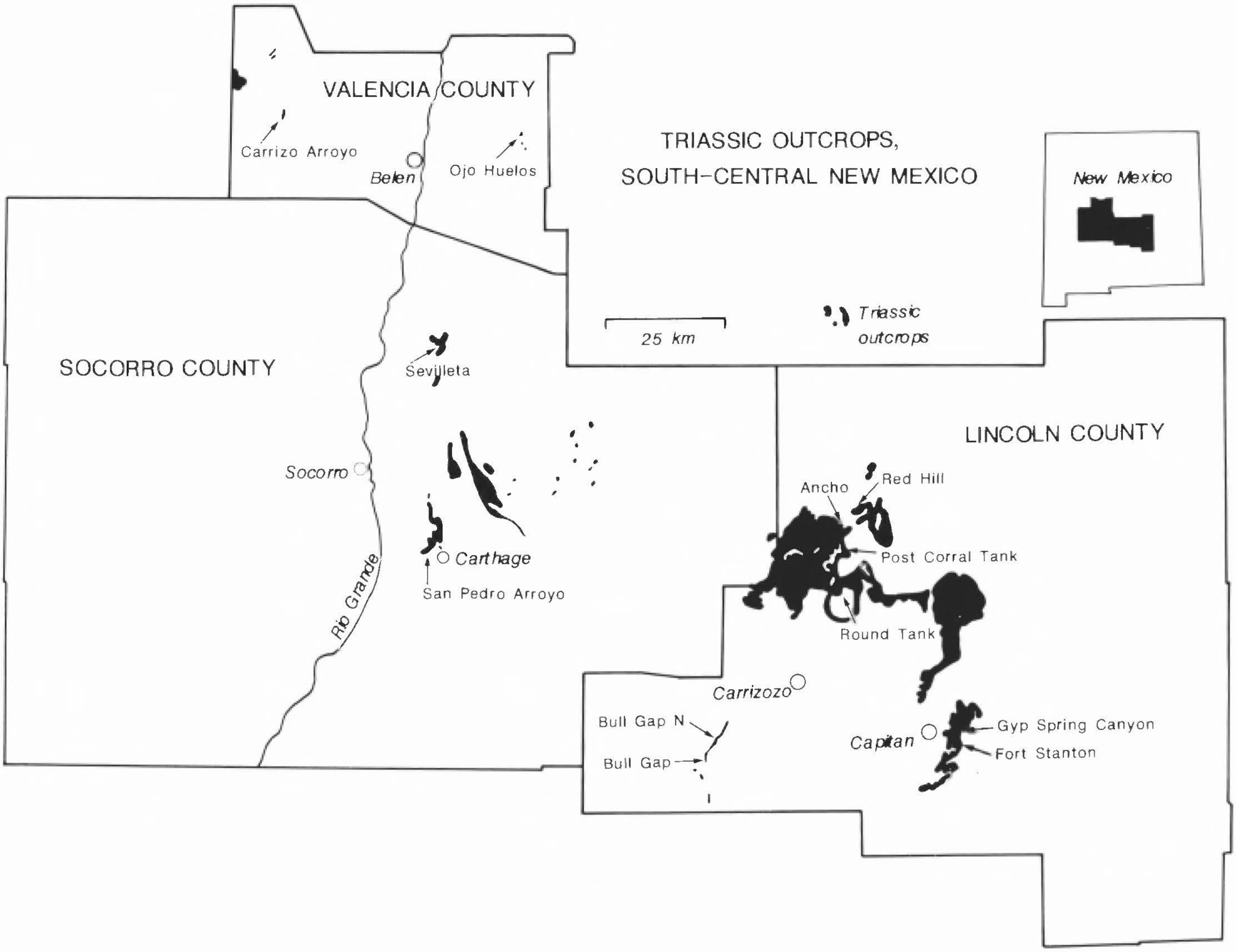


FIGURE 1. Distribution of Triassic strata in south-central New Mexico (after Dane and Bachman, 1965).

Grayish red sandstone is the dominant lithology (60%+) of the Moenkopi Formation in south-central New Mexico (Figs. 3, 4A, C), as it is across the northern half of the state (Lucas and Hunt, 1987, 1989; Lucas and Hayden, 1989a, b). Most of the Moenkopi sandstones are very fine- to fine-grained, micaceous litharenites that are trough-crossbedded or ripple laminated (e.g., Fig. 4C, E). A few sandstones are graywackes, and most contain relatively fresh biotites, implying a nearby volcanic source. Dips of crossbeds in these sandstones in south-central New Mexico indicate paleoflow to the north and the northwest. Moenkopi mudstones and siltstones also are mostly grayish red and are not bentonitic. Moenkopi conglomerates (e.g., Fig. 4D) are composed almost exclusively of intrabasinal pebbles of siltstone, mudstone and nodular calcrete. However, one conglomerate bed in the upper Moenkopi (Fig. 3, Bull Gap N section, unit 28) contains extrabasinal clasts of quartzite and chert.

The Moenkopi Formation in south-central New Mexico is readily distinguished from underlying red beds of the Artesia Formation on the basis of color, mineralogy and sedimentary structures. Artesia red beds are reddish brown, gypsiferous, dominated by quartzose, texturally mature fine sandstones and siltstones that are rarely trough-crossbedded (bioturbated/massive and laminar/ripple laminated are the dominant bedforms) and contain only a few limestone-pebble conglomerates. In contrast, Moenkopi red beds are grayish red, devoid of gypsum, dominated by micaceous litharenites and graywackes that are typically trough crossbedded and frequently contain intraformational conglomerates. Younger Shinarump and Santa Rosa Formation conglomerates are extrabasinal in origin and consist of siliceous pebbles of quartzite and chert in a subarkose/quartzarenite matrix and thus are readily distinguished from all but a rare Moenkopi conglomerate. Red beds of the San Pedro Arroyo Formation in south-central New Mexico are dominated by bentonitic mudstones and thus are not easily mistaken for Moenkopi red beds.

Principal outcrops of the Anton Chico Member of the Moenkopi Formation in south-central New Mexico are the following:

1. Carrizo Spring, on the eastern edge of the Lucero uplift, sec. 6, T6N, R2W, Valencia County, where 43.5 m of Moenkopi disconformably overlie the San Andres and are culminated by the mottled strata overlain by the San Pedro Arroyo Formation (Lucas and Hayden, 1989a, fig. 4B–C; Fig. 3). Indeed, most of the Triassic rocks along the eastern edge of the Lucero uplift mapped by Callender and Zilinski (1976) as Chinle Formation actually are Moenkopi Formation.

2. South of Ojo Huelos, 34°34′46″N, 106°46′42″W, Valencia County, where at least 10 m of pale brown, brownish gray and pale red, trough-crossbedded micaceous litharenite probably pertain to the Moenkopi Formation. However, faulting and cover in this area obscures the upper and lower contacts of this unit.

3. Palo Duro Canyon, Sevilleta Grant, sec. 22 (unsurveyed), T1N, R2E, Socorro County (Fig. 3), where 61.2 m of Moenkopi Formation

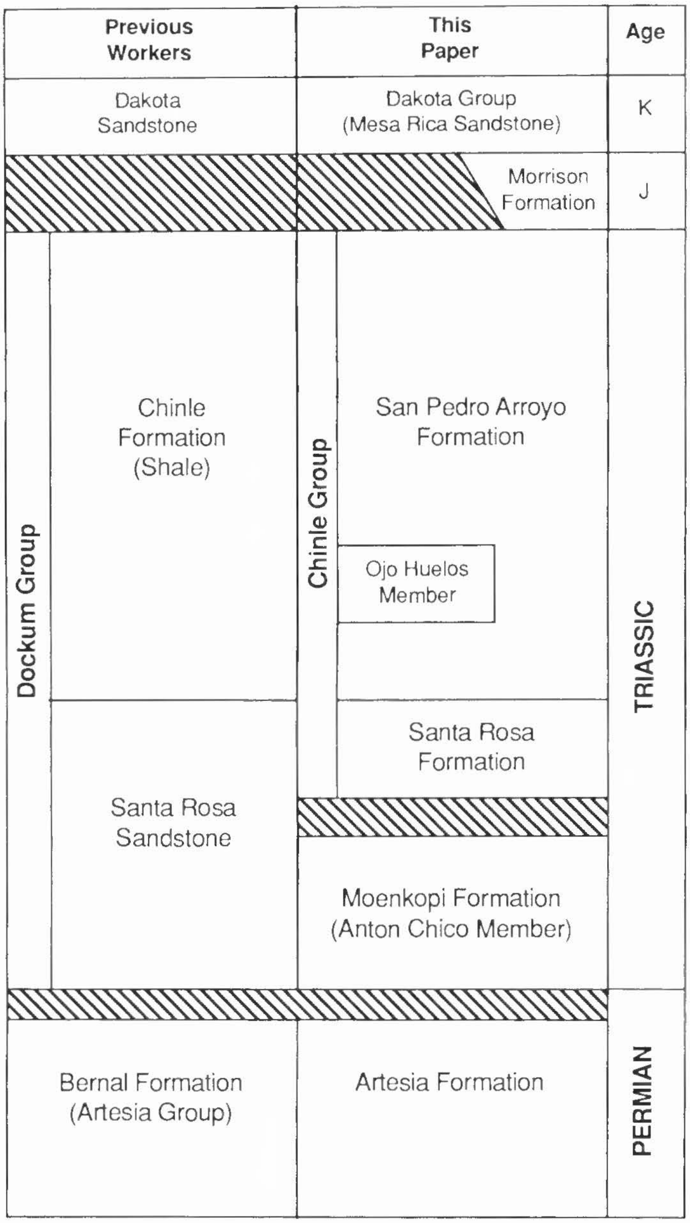


FIGURE 2. Comparison of stratigraphic nomenclature of Triassic rocks in south-central New Mexico used by previous workers with that advocated in this paper.

disconformably overlie the Artesia Formation and are disconformably overlain by the San Pedro Arroyo Formation (Stewart et al., 1972, sec. NM-17; Hayden et al., 1990). Myers et al. (1986) mapped these Moenkopi strata as Dockum Formation.

4. Carthage, secs. 3, 4, 5, 8 and 9, T5S, R2E, Socorro County, where structural complexity precludes measurement of the entire thickness of the Moenkopi Formation, although its lower contact with the Artesia Formation and upper contact with the Shinarump Formation are well exposed (Figs. 3, 4A). Moenkopi strata in the Carthage area have long been assigned to either the Chinle Formation (e.g., Smith et al., 1983, fig. 1-60.55), Dockum Formation (Group) (e.g., Wilpolt and Wanek, 1951; Budding, 1963) or Santa Rosa Formation (e.g., Fagrelius, 1982). Hunt and Lucas (1988) first identified Moenkopi strata in the Carthage area and claimed they were the southeasternmost outcrops of the formation. However, here I extend the distribution of the Moenkopi into Lincoln County, well to the southeast, about 75 km.

5. Ancho–Red Hill, secs. 1 and 22, T4S, R11E, Lincoln County, where 23–27 m of Moenkopi Formation are present between the San Andres and Santa Rosa Formations (Figs. 3, 4C). Moenkopi strata here were previously included in the Santa Rosa Formation (Budding, 1964; Smith, 1964).

6. Bull Gap, west of Oscura, secs. 14 and 27, T9S, R8E, Lincoln County, where as much as 102 m of Moenkopi Formation are present between the Artesia Formation and the Lower Cretaceous Mesa Rica Sandstone of the Dakota Group (Figs. 3, 4B, D, E, F). Darton (1928, pl. 42) first mapped these rocks as "Dockum(?) group" and they have since been assigned to the Dockum (Kottlowski, 1963; Weber, 1964; Osburn and Arkell, 1986). However, the lithology of these rocks is not characteristic of Upper Triassic strata elsewhere in south-central New Mexico or in southeastern New Mexico. Instead, the Triassic strata exposed at Bull Gap are identical to Moenkopi strata to the north and northwest.

Mottled strata

Stewart et al. (1972) applied the term "mottled strata" to color-mottled rocks at the base of the Chinle Formation on the Colorado Plateau. These are pedogenically modified siltstones, mudstones and sandstones that commonly underlie the Shinarump Formation (Lucas and Hayden, 1989a). They represent a paleo-weathering profile developed on pre-Tr-3-unconformity, Permian or Triassic (Moenkopi) strata. As such, the mottled strata are not easily thought of as a stratigraphic unit because they may cut across stratigraphy, although on the Colorado Plateau the mottled strata are included in the Chinle Formation (Stewart et al., 1972).

Lucas et al. (1990) used the term mottled strata as an informal unit in the Sangre de Cristo Mountains of northeastern New Mexico. I also use the term mottled strata as an informal unit in south-central New Mexico. Here, the mottled strata are present at three sections I measured—Carrizo Arroyo, Ojo Huelos and Sevilleta (Fig. 3). They are as much as 5.0 m of orange, red, gray and pink mottled silty sandstone, siltstone and silica-pebble conglomerate. Some of the silica-pebble conglomerate may represent incised-channel lags equivalent to the Shinarump Formation, but in general the mottled strata predate the Tr-3 unconformity. Pedogenically modified, color-mottled beds at the top of the Moenkopi Formation below the Dakota Group at Bull Gap (Figs. 3, 4F) could be assigned to the mottled strata as well. I do not make such an assignment because these strata are beneath a compound unconformity that encompasses Tr-3 through K-O time (Pipiringos and O'Sullivan, 1978) and thus may represent a significantly younger pedogenic event(s) than other mottled strata in south-central New Mexico. Nevertheless, these color-mottled beds at Bull Gap are weathered Moenkopi strata, not the thin interval of Jurassic Morrison Formation identified by Hunt and Lucas (1987), Hayden et al. (1990) and Lucas (1991c) at some other locations in south-central New Mexico.

Shinarump and Santa Rosa Formations

I assign an interval of silica-pebble conglomerate and sandstone in south-central New Mexico that rests disconformably on the mottled strata or Moenkopi Formation and is overlain by the San Pedro Arroyo Formation to the Shinarump and Santa Rosa Formations. The Shinarump Formation is the basal formation of the Chinle Group on the Colorado Plateau, whereas the Santa Rosa Formation lies at the base of the Chinle Group in east-central New Mexico (Lucas, 1991b). Since south-central New Mexico is between these two Chinle Group terranes, use of Shinarump or Santa Rosa for this interval is somewhat arbitrary (cf. Lucas, 1991a). Regardless of the nomenclature, however, it is important to recognize the temporal and depositional equivalence of Shinarump and Santa Rosa strata across south-central New Mexico (Lucas, 1991b).

My choice is to use Shinarump along the Colorado Plateau edge in Valencia County (Carrizo Arroyo) and in and along the eastern edge of the Rio Grande rift (Carthage). Here, the Shinarump is a relatively thin (less than 6 m thick), discontinuous unit, commonly consisting of trough-crossbedded, silica-pebble conglomerate (Fig. 3).

To the east, in Lincoln County, I apply the name Santa Rosa Formation to a thicker and more persistent unit of both silica-pebble con-

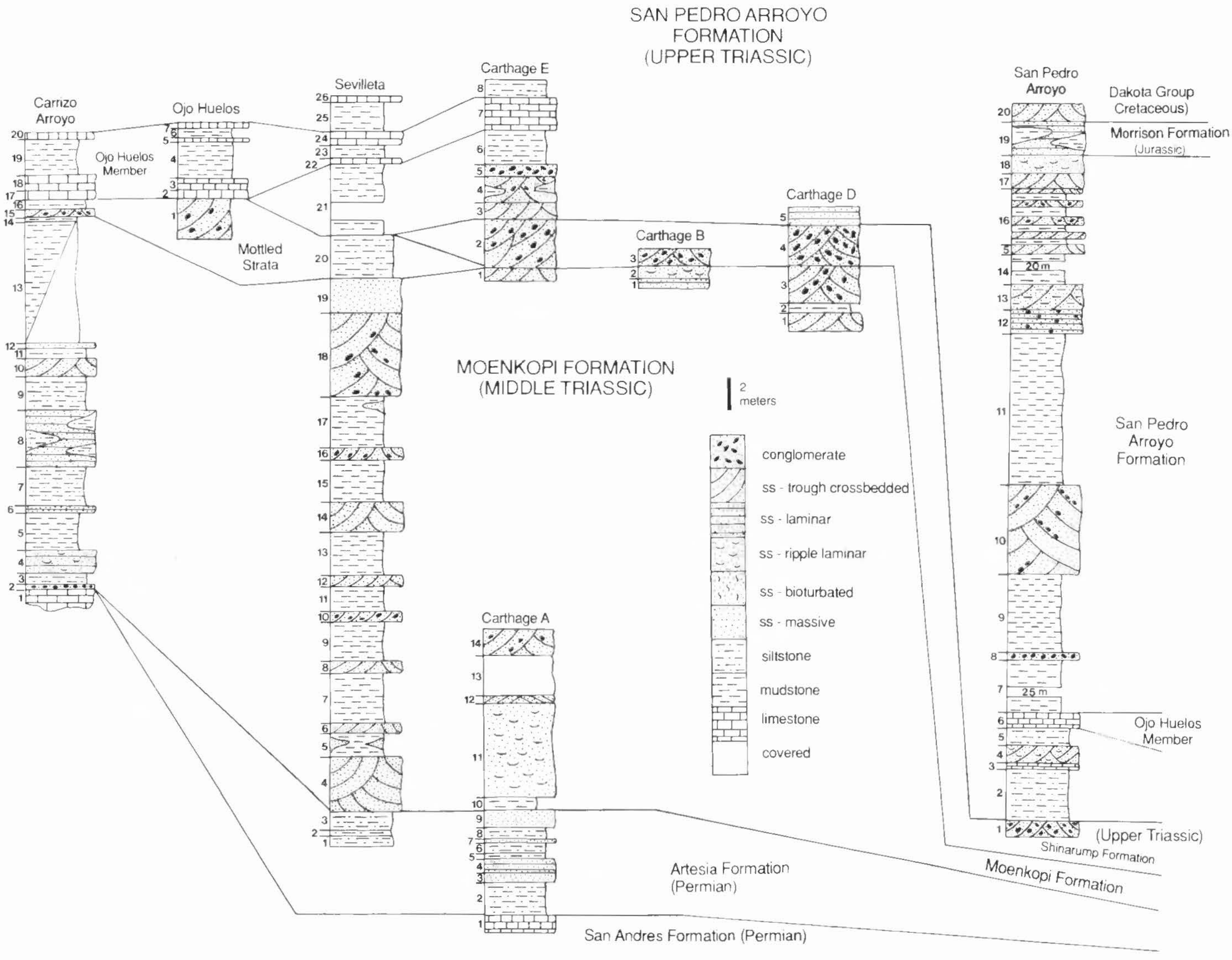


FIGURE 3. Measured stratigraphic sections of Triassic rocks in south-central New Mexico. See Fig. 1 and Appendix for locations of sections and lithologic descriptions of numbered units.

glomerates and non-conglomeratic sandstones (Fig. 3, 5A–B). This unit is readily correlated to the north and northeast with Santa Rosa Formation outcrops in nearby Torrance, Guadalupe and De Baca Counties (Kelley, 1972a, b).

The Santa Rosa Formation in Lincoln County of previous workers included Moenkopi strata, so their thickness estimates are inaccurate. The restricted Santa Rosa Formation employed here is 13–26 m thick and consists mostly of grayish yellow and yellowish brown, silica-pebble conglomerate and micaceous subarkose. However, at Fort Stanton an 11-m-thick interval of sandy mudstone is also present in the Santa Rosa Formation (Fig. 3). The lithology of the Santa Rosa Formation in Lincoln County most closely resembles that of the Tecolotito Member of the Santa Rosa Formation to the north, although the tripartite (sandstone-mudstone-sandstone) section at Fort Stanton is reminiscent of the three-fold subdivision of the Santa Rosa in east-central New Mexico (Lucas and Hunt, 1987).

San Pedro Arroyo Formation

The mudstone-dominated section above the Santa Rosa Formation in south-central New Mexico has long been referred to the Chinle Formation or Chinle Shale (Fig. 2). However, this use of Chinle Formation is unsatisfactory because it excludes Shinarump/Santa Rosa strata, which are part of the Chinle Formation on the Colorado Plateau (Stewart et al., 1972). In addition, raising Chinle to group rank (Lucas, 1991b) makes it impossible to continue to use Chinle Formation in south-central New Mexico for the upper, mudstone-dominated portion of the Upper Triassic section. Furthermore, I am unable to assign these mudstone-dominated strata to already named Chinle Group units to the northwest, north or east. They are lithologically distinct from these units, particularly because of their overall sandiness and the presence (in Valencia-Socorro Counties) of a persistent limestone interval near their base. For these reasons, the name Chinle Formation as previously used in south-central New Mexico is unsatisfactory, and a new stratigraphic term needs to be introduced.

I thus coin the name San Pedro Arroyo Formation for the mudstone-dominated Chinle Group strata above the Shinarump and Santa Rosa Formations in south-central New Mexico. The name is from San Pedro Arroyo, a dry tributary of the Rio Grande just north of NM Highway 380, principally in the northern fourth of T5S, R2E, Socorro County (Fig. 1). The type section of the San Pedro Arroyo Formation is located here (Figs. 3, 5D–E) as is a broad outcrop belt of characteristic and fossiliferous strata of the formation.

At its type section (Fig. 3), the San Pedro Arroyo Formation is approximately 123 m thick and is dominated by mudstone (67% of the

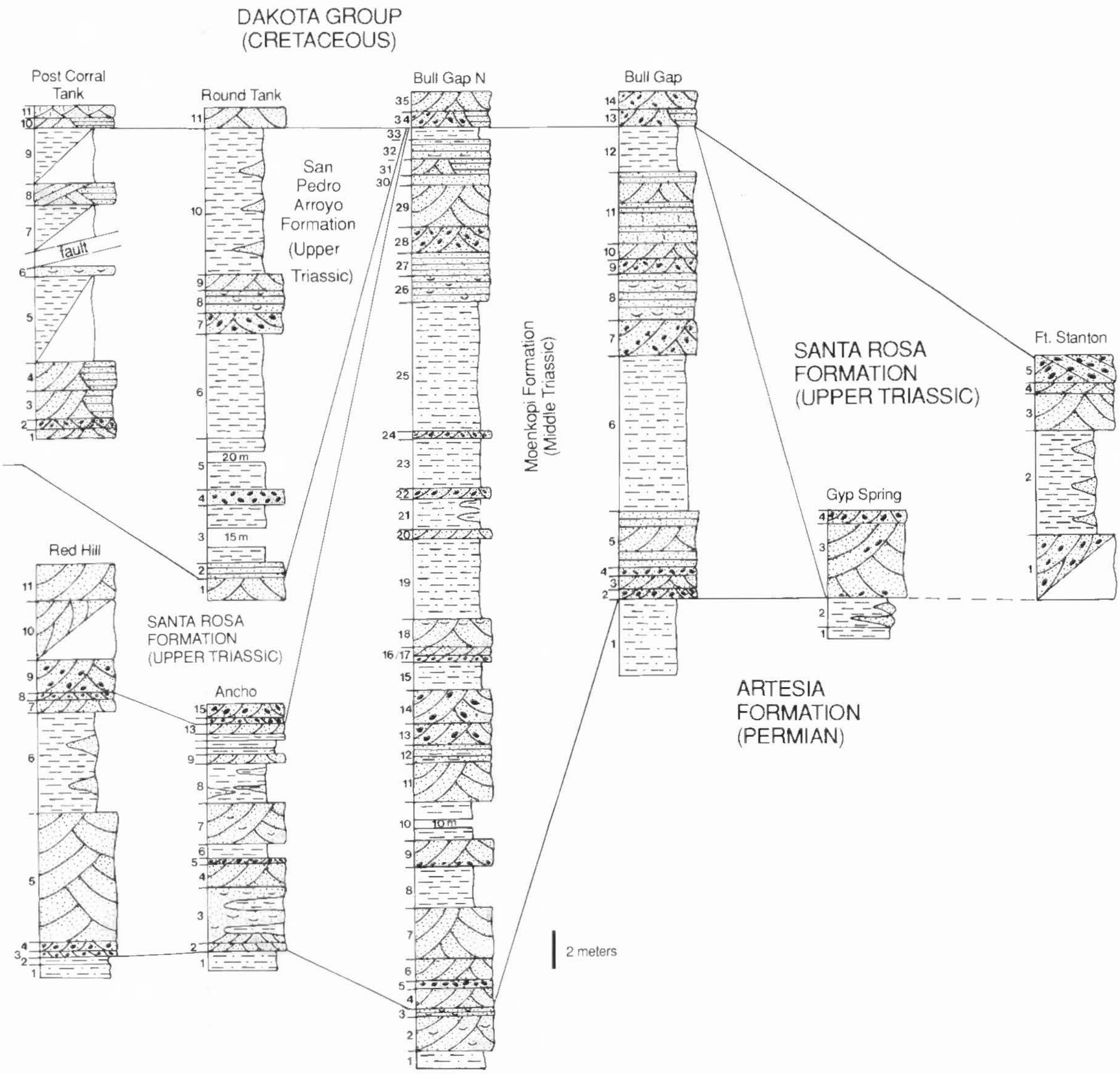


FIGURE 3 (continued)

measured section) with much less sandstone (12%), sandstone and conglomerate (11%) and siltstone (8%) and very little limestone (1%). The mudstones are bentonitic and variegated grayish red, greenish gray, grayish purple and reddish brown. The sandstones (e.g., Fig. 5C) are grayish purple and grayish red, trough crossbedded, laminar and ripple-laminated, micaceous litharenites that often are interlaced with intrabasinal conglomerates composed of mudstone and calcrete clasts. Late Triassic fossil unionid clams, amphibians and reptiles occur in the sandstone/conglomerate of units 8 and 10 of the type section (see below). San Pedro Arroyo Formation siltstones are grayish red to brown. Other than a thin nodular limestone bed near the base of the section, the only limestone at the type section is a prominent and persistent, 1.6-m-thick bed of pisolitic limestone 10.4 m above the base of the formation. This unit, the Ojo Huelos Member of the San Pedro Arroyo Formation, splits the formation in Valencia and Socorro Counties into informal lower and upper members (Fig. 3).

The San Pedro Arroyo Formation is present across Valencia, Socorro and Lincoln Counties from the eastern edge of the Lucero uplift at Carrizo Spring to the Capitan Mountains (Figs. 1, 5D–G). Its 123-m-thick type section represents the maximum known thickness of the formation and is comparable to an estimated maximum thickness of 400 ft for the "Chinle Formation" in Lincoln County (Smith, 1964). Across its outcrop extent, the San Pedro Arroyo Formation rests on older Triassic strata of the Shinarump, Santa Rosa or Moenkopi Formations. A prominent disconformity always marks its upper contact with the Jurassic Morrison Formation or Cretaceous Dakota Group.

Ojo Huelos Member

In Socorro and Valencia Counties, a prominent interval of limestone is present in the lower part of the San Pedro Arroyo Formation. This unit is 1.6 to 7.4+ m thick and can be recognized from Carrizo Spring, Valencia County to Carthage, Socorro County, a distance of about 100 km (Figs. 1, 3, 5G–H). I name this limestone unit the Ojo Huelos Member of the San Pedro Arroyo Formation. Ojo Huelos is a spring in the Hubbell fault zone of Valencia County just north of the type section of the Ojo Huelos Member (Reiche, 1949; Kelley, 1977).

At its type section, the Ojo Huelos Member is 7.4+ m thick and rests on the lower member of the San Pedro Arroyo Formation (Lucas and Hayden, 1988; Lucas et al., 1988). Three prominent limestone beds split by yellowish gray sandy mudstone comprise the Ojo Huelos Member type section. The limestones range from gray micrite to yellow pisolite. The uppermost sandy mudstone and limestone of the type section produce fossils of ostracodes and vertebrates indicative of a Late Triassic (late Carnian) age (see below). The top of the Ojo Huelos

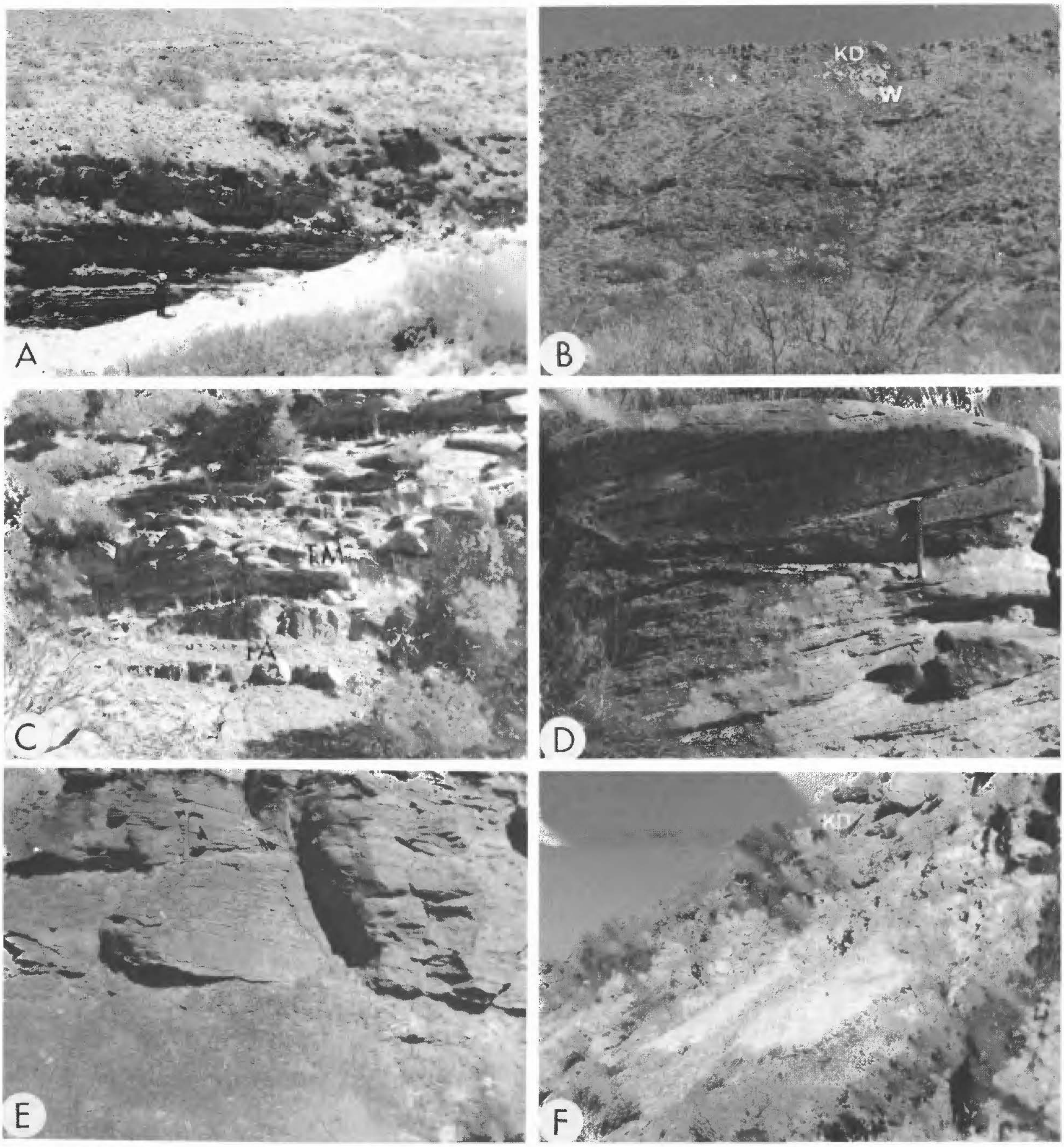
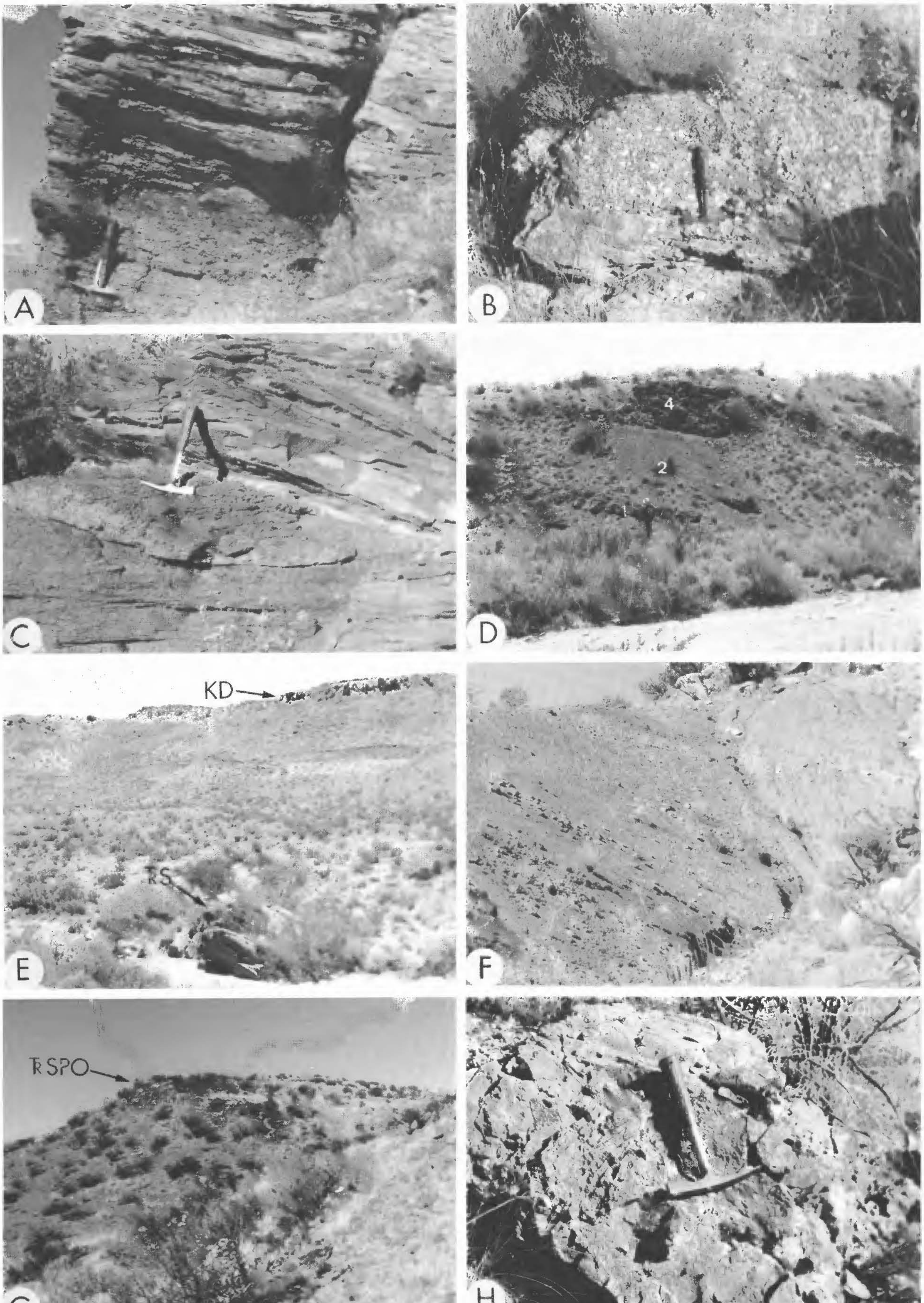


FIGURE 4. Photographs of Moenkopi Formation strata in Socorro and Lincoln Counties, New Mexico. A, Ripple-laminar-sandstone-dominated Moenkopi Formation at Carthage A section. B, Overview of Bull Gap N section where Moenkopi strata are topped by a deeply weathered horizon (w) overlain by the Lower Cretaceous Mesa Rica Sandstone of the Dakota Group (KD). C, Trough-crossbedded sandstone and conglomerate of the Moenkopi Formation (TrM) above siltstones of the Permian Artesia Formation (PA) at the Red Hill section. D, Basal, trough-crossbedded conglomerate and sandstone of the Moenkopi Formation, unit 2 of the Bull Gap section. E, Typical Moenkopi ripple-laminar sandstone above muddy siltstone, units 25–26 of the Bull Gap N section. F, Deeply weathered horizon at top of Moenkopi Formation beneath the Lower Cretaceous Mesa Rica Sandstone of the Dakota Group (KD) (also see Fig. 4B).

FIGURE 5. Photographs of Upper Triassic strata in south-central New Mexico. A, Trough-crossbedded silica-pebble conglomerate and sandstone of the Santa Rosa Formation, unit 9 at the Red Hill section. B, Silica-pebble conglomerate of the Santa Rosa Formation, unit 4 of the Gyp Spring Canyon section. C, Trough-crossbedded sandstone in the upper part of the San Pedro Arroyo Formation, unit 4 of the Post Corral Tank section. D, Base of the type section of the San Pedro Arroyo Formation with numbering of selected units (cf. Fig. 3). E, Overview of the type area of the San Pedro Arroyo Formation showing subjacent Shinarump Formation (TrS) and superjacent Dakota Group (KD). F, Characteristic bluish, bentonitic mudstone with calcrete nodules of lower part of San Pedro Arroyo Formation, unit 3 of Round Tank section. G, Lower part of San Pedro Arroyo Formation at Sevilleta section where Ojo Huelos Member (TrSPO) caps a ridge. H, Close-up of limestone of Ojo Huelos Member at Sevilleta section.


A
B
C
D
4
2
1
E
KD
TRS
F
G
TRSPO
H

Member is not exposed at its type section, but other sections described here at Sevilleta and Carthage (Figs. 3, 5G–H) indicate it is overlain by siltstone or mudstone of the upper member of the San Pedro Arroyo Formation.

The lithology and paleontology of the Ojo Huelos Member indicate it is of lacustrine origin (Lucas and Hayden, 1988). Assuming a minimum of 8 km of east-west extension across the Rio Grande rift since the Late Triassic (Woodward, 1977), the outcrop distribution of the Ojo Huelos Member suggests the presence of a single or separate lakes in south-central New Mexico over an area of 1900 km^2. It is also worth noting that the northernmost extent of the Ojo Huelos Member, at Carrizo Arroyo on the western side of the Rio Grande rift and near Ojo Huelos on the eastern side of the rift, are only offset about 5 km in a north-south direction. This does not support the concept of 33–42 km of left offset of the rift edge due to Laramide strike-slip faulting advocated by some workers (Kelley, 1982).

PALEONTOLOGY

The only fossil known from the Moenkopi Formation in south-central New Mexico is an intercentrum of a capitosauroid amphibian from unit 14 of the Carthage E section. This fossil is indicative of an Early or Middle Triassic age (Lucas and Morales, 1985).

The Shinarump and Santa Rosa Formations in south-central New Mexico have only produced undiagnostic pieces of petrified wood. In the Round Tank section in Lincoln County (Fig. 3), unit 4 in the lower part of the San Pedro Arroyo Formation is an intraformational conglomerate that produces isolated teeth and scutes of phytosaurs, indicative of the Late Triassic, but not of a more precise age. A mudstone in the lower part of the San Pedro Arroyo Formation at NMMNH locality 1329 (SW¼ SE¼ NE¼ sec. 8 [unsurveyed], T1S, R2E) near the Sevilleta section (Fig. 3), produced an interclavicle fragment of *Metoposaurus* (Fig. 6K) suggestive of a late Carnian age.

Reiche (1949) first mentioned the presence of Triassic ostracodes in the limestones near Ojo Huelos. Ken Kietzke and I have collected an extensive microfauna of ostracodes and vertebrates from unit 6 and a small megafauna from unit 7 of the type section of the Ojo Huelos Member. The microfauna is dominated by isolated teeth and scales of actinopterygians (Fig. 6H), neoselachians (Fig. 6E–F) and the hybodont *Lissodus* cf. *L. humblei* as well as ostracodes that represent two species of *Darwinula* (Fig. 6A–C) and ?*Gerdalia triassica* (Fig. 6D). The macrofauna is limited to phytosaur teeth and scutes and the natural mold of the palate of a large labyrinthodont amphibian which I tentatively identify as *Metoposaurus* (Fig. 6I). The ostracodes, *Lissodus* and *Metoposaurus* are suggestive of a late Carnian age (Kietzke, 1989) and correlation with lower Chinle Group units like the Bluewater Creek and Monitor Butte Formations on the Colorado Plateau and the Los Esteros Member of the Santa Rosa Formation, Garita Creek and Tecovas Formations on the High Plains (Lucas, 1991a, b).

Units 8 and 10 in the type section of the San Pedro Arroyo Formation produce fragmentary fossils of metoposaurid amphibians and phytosaurs (e.g., Fig. 6J). Unit 10 also contains a localized coquina bed of unionid bivalves (Fig. 6G). These fossils indicate a Late Triassic age but are of no more precise biochronological significance.

Case (1916) reported Triassic "dinosaur" fossils from red beds near Carthage, Socorro County. His locality description ("close to the lime kiln about half way up to the base of the Cretaceous the writer found a small bed of conglomerate": Case, 1916, p. 708) suggests unit 10 of the San Pedro Arroyo section, and the lower conglomerate he mentions probably is unit 8 of this section (Fig. 3). Specimens at the University of Michigan (UM) that document his report are UM 9651, vertebral centra, and UM 9651, two humerus fragments (Fig. 6L–N), both of which pertain to phytosaurs and indicate a Late Triassic age.

CORRELATION

The correlation of Triassic strata in south-central New Mexico advocated here (Fig. 7) reflects the following conclusions:

1. The Anton Chico Member of the Moenkopi Formation in south-central New Mexico is equivalent to Anton Chico strata to the north which are of early Anisian age (Lucas and Morales, 1985; Lucas and Hunt, 1987, 1989). The presence of a capitosauroid in the Anton Chico Member at Carthage and the lithology and stratigraphic position of the Anton Chico in south-central New Mexico support this correlation and age assignment.
2. The Tr-3 unconformity separates Upper Triassic Shinarump and Santa Rosa strata from underlying Middle Triassic Moenkopi strata in south-central New Mexico.
3. Lithology and stratigraphic position support correlation of Shinarump and Santa Rosa strata in south-central New Mexico with Shinarump and with lower(?) Santa Rosa (Tecolotito Member) strata in east-central New Mexico.
4. The lower member and the Ojo Huelos Member of the San Pedro Arroyo Formation are of late Carnian age, correlative with lower Chinle Group strata to the northwest and north.
5. The upper member of the San Pedro Arroyo Formation is of Late Triassic age, but current evidence will not allow a more precise age determination. I favor the possibility of an unconformity between the Ojo Huelos Member and overlying red beds, suggesting correlation of the upper member of the San Pedro Arroyo Formation with upper Chinle Group units (Fig. 7). However, current data do not rule out the possibility that the upper member, and thus the entire San Pedro Arroyo Formation, is only equivalent to the lower part of the Chinle Group.

ACKNOWLEDGMENTS

I thank B. Allen, W. C. Beck, R. Colpitts, S. Hayden, A. Hunt, K. Kietzke, P. Reser and P Sealey for information and/or assistance in the field. A. Hunt and J. Lorenz reviewed the manuscript and provided helpful comments.

REFERENCES

Allen, J. E. and Jones, S. M., 1951, Preliminary stratigraphic section Capitan quadrangle New Mexico: Roswell Geological Society, Guidebook 5, chart.

Bates, R. L., Wilpolt, R. H., MacAlpin, A. J. and Vorbe, G., 1947, Geology of the Gran Quivira quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 26, 57 p.

Budding, A. J., 1963, Field trip 7, Carthage area: New Mexico Geological Society, Guidebook 14, p. 74–77.

Budding, A. J., 1964, Geologic outline of the Jicarilla Mountains, Lincoln County, New Mexico: New Mexico Geological Society, Guidebook 15, p. 82–86.

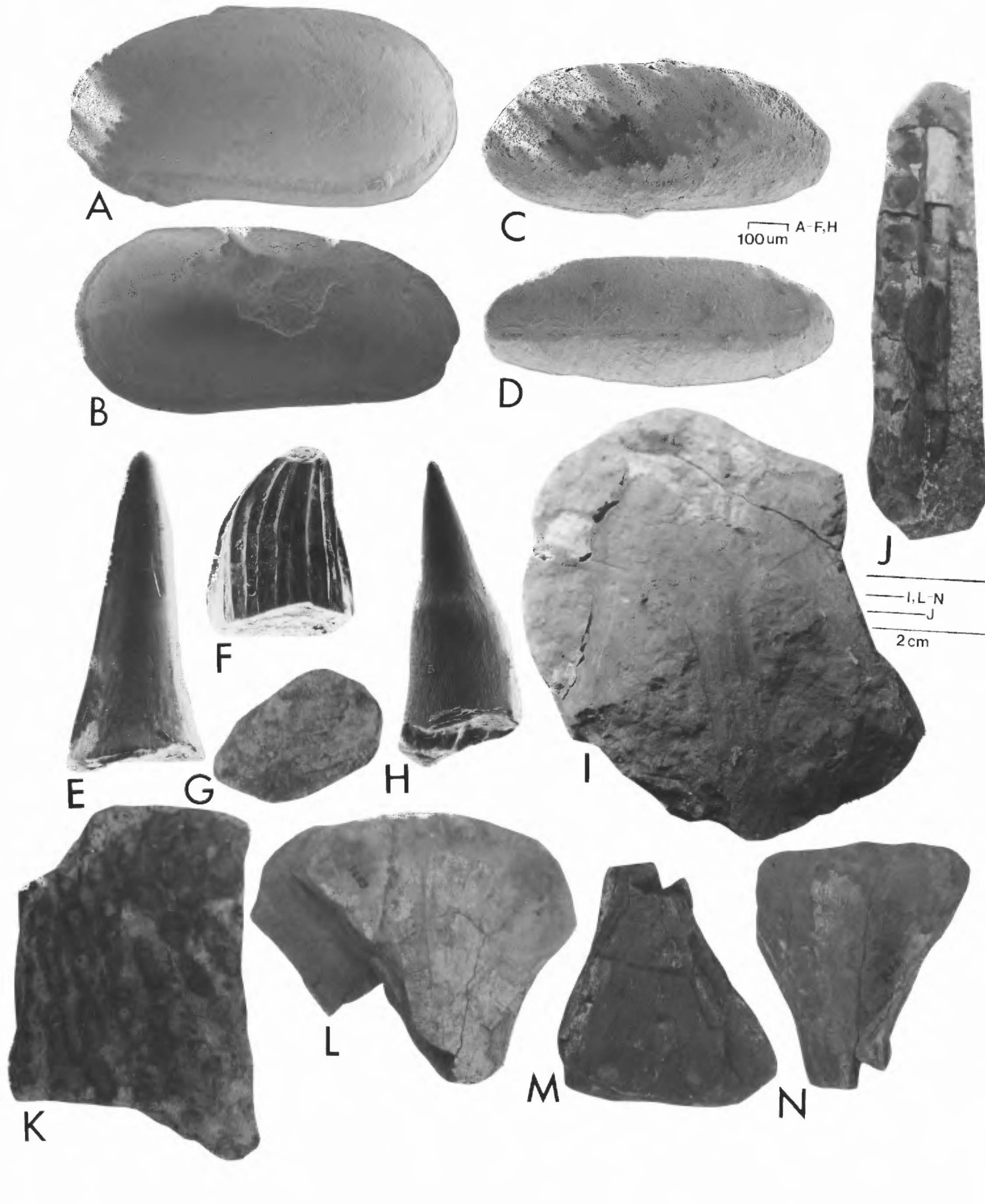
Callender, J. F. and Zilinski, R. E., Jr., 1976, Kinematics of Tertiary and Quaternary deformation along the eastern edge of the Lucero uplift, central New Mexico: New Mexico Geological Society, Special Publication 6, p. 53–61.

Case, E. C., 1916, Further evidence bearing on the age of the red beds in the Rio Grande valley, New Mexico: Science, v. 44, p. 708–709.

Dane, C. H. and Bachman, G. O., 1965, Geological map of New Mexico: Denver, U.S. Geological Survey, scale 1:500,000.

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, 356 p.

FIGURE 6. Selected Late Triassic fossils from south-central New Mexico. A, *Darwinula* sp., NMMNH P-18185, lateral view of left valve. B, *Darwinula* sp., NMMNH P-18186, lateral view of right valve. C, *Darwinula* sp., NMMNH P-18187, lateral view of right valve. D, ?*Gerdalia triassica*, NMMNH P-18188, lateral view of right valve. E–F, Selachian teeth, NMMNH P-18189 and 18190. G, *Unio* sp., NMMNH P-18191. H, Actinopterygian tooth, NMMNH P-18192. I, Impression of palate of *Metoposaurus* sp., NMMNH P-18193. J, Occlusal view of phytosaur jaw fragment, NMMNH P-18194. K, Interclavicle fragment of *Metoposaurus* sp., NMMNH P-18195. L–N, UM (University of Michigan) 9653, phytosaur humerus fragments reported by Case (1916) from red beds near Carthage, Socorro County.


A
B
C
D
100 um A–F,H
E
F
G
H
I
J
G
I, L–N
J
2 cm
K
L
M
N

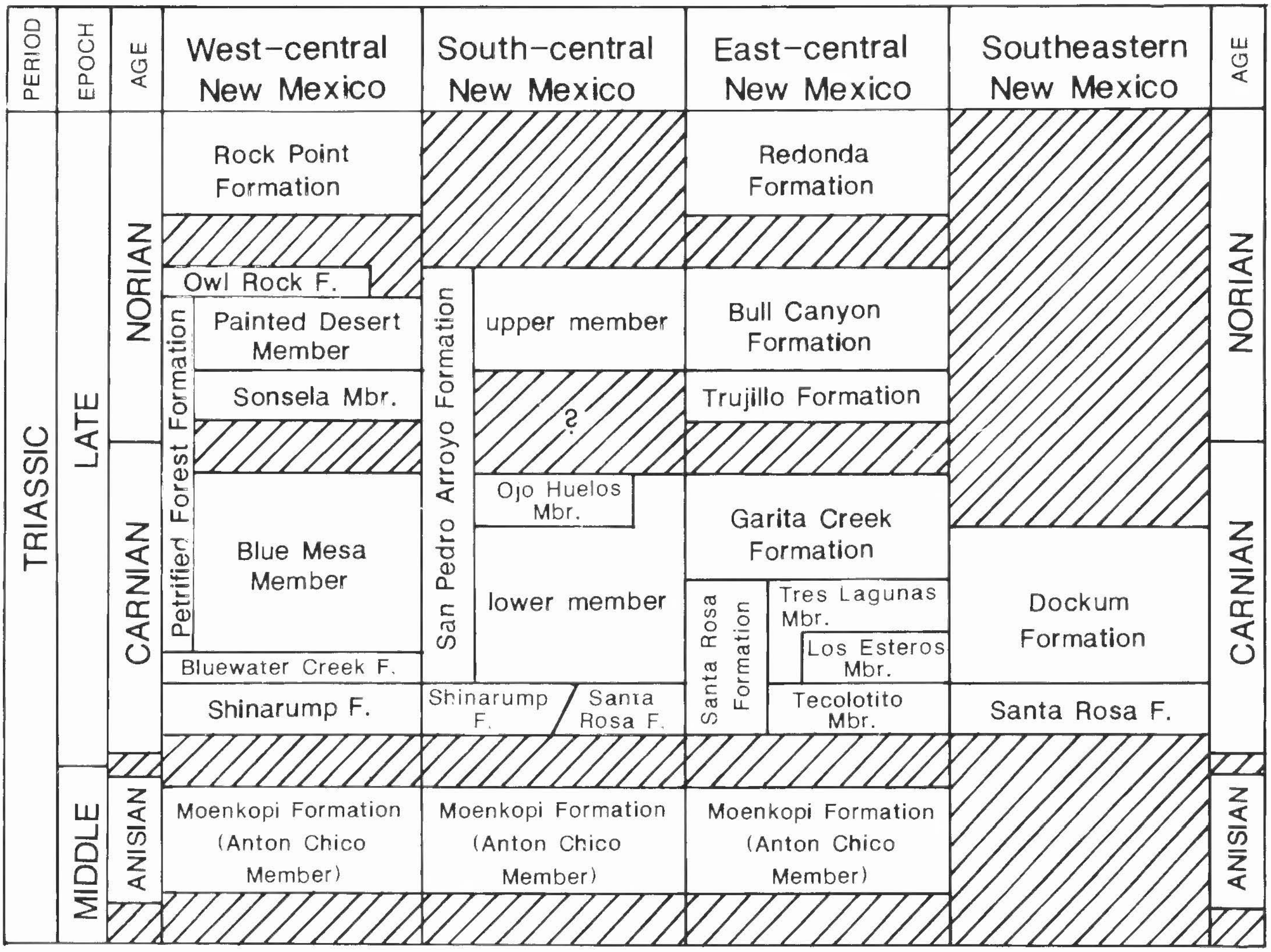


FIGURE 7. Correlation of Triassic strata in south-central New Mexico (after Lucas, 1991b).

Fagrelius, K. H., 1982, Geology of the Cerro del Viboro area, Socorro County, New Mexico [M.S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 138 p.

Goddard, E. N., Trask, P. D., DeFord, R. K., Rove, O. N., Singewald, J. T., Jr. and Overbeck, R. M., 1984, Rock-color chart: Boulder, Geological Society of America.

Haines, R. A., 1968, The geology of the White Oaks–Patos Mountain area, Lincoln County, New Mexico [M.S. thesis]: Albuquerque, University of New Mexico, 63 p.

Hayden, S. N., Lucas, S. G., Hunt, A. P. and Beck, W. C., 1990, Triassic-Jurassic stratigraphy, Palo Duro Canyon, Sevilleta Grant, Socorro County, New Mexico: New Mexico Geology, v. 12, p. 65.

Hunt, A. P. and Lucas, S. G., 1987, Southeasternmost outcrops of the Morrison Formation in the Carthage area, Socorro County, New Mexico: New Mexico Geology, v. 9, p. 58–62.

Hunt, A. P. and Lucas, S. G., 1988, Triassic stratigraphy, Carthage area, Socorro County, New Mexico and the southeasternmost outcrops of the Moenkopi Formation: New Mexico Geology, v. 10, p. 45.

Kelley, V. C., 1971, Geology of the Pecos country, southeastern New Mexico: New Mexico Bureau of Mines and Mineral Resources, Memoir 24, 78 p.

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

Kelley, V. C., 1972b, Triassic rocks of the Santa Rosa country: New Mexico Geological Society, Guidebook 23, p. 84–90.

Kelley, V. C., 1977, Geology of Albuquerque basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Memoir 33, 60 p.

Kelley, V. C., 1982, The right-relayed Rio Grande rift, Taos to Hatch, New Mexico: New Mexico Geological Society, Guidebook 33, p. 147–151.

Kelley, V. C. and Wood, G. H., Jr., 1946, Lucero uplift, Valencia, Socorro, and Bernalillo Counties, New Mexico: U.S. Geological Survey, Oil and Gas Investigations Map 47.

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.

Kottlowski, F. E., 1963, Paleozoic and Mesozoic strata of southwestern and south-central New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 79, 100 p.

Lucas, S. G., 1991a, 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., 1991b, The Chinle Group: revised stratigraphy and chronology of Upper Triassic nonmarine strata in the western United States: Museum of Northern Arizona Bulletin, in press.

Lucas, S. G., 1991c, Southeasternmost outcrops of the Morrison Formation, Capitan, Lincoln County, New Mexico: New Mexico Geological Society, Guidebook 42.

Lucas, S. G. and Hayden, S. N., 1988, Late Triassic lake in central New Mexico: Abstracts of the Symposium on Southwestern Geology and Paleontology 1988, p. 12.

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

Lucas, S. G. and Hayden, S. N., 1989b, Middle Triassic Moenkopi Formation, Nacimiento Mountains, north-central New Mexico; *in* Lorenz, J. C. and Lucas, S. G., eds., Energy frontiers in the Rockies: Albuquerque, Albuquerque Geological Society, p. 16–17.

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 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 in the 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 Morales, M., 1985, Middle Triassic amphibian from basal Santa Rosa Formation, east-central New Mexico: New Mexico Geological Society, Guidebook 36, p. 56–58.

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

Lucas, S. G., Kietzke, K. K., Hayden, S. N. and Allen, B. D., 1988, Triassic strata in the Hubbell Springs fault zone, Valencia County, New Mexico: New Mexico Geology, v. 10, p. 65.

Myers, D. A., Sharps, J. A. and McKay, E. J., 1986, Geologic map of the Becker SW and Cerro Montoso quadrangles, Socorro County, New Mexico: U.S. Geological Survey, Miscellaneous Investigations Series I-1567, scale 1:24,000.

Osburn, J. C. and Arkell, B. W., 1986, Roadlog from Ruidoso to Tularosa, Oscura, Carrizozo, Valley of Fires, White Oaks, Capitan, and back to Ruidoso; *in* Ahlen, J. L. and Hanson, M. E., eds., Southwest section of AAPG transactions and guidebook of 1986 convention Ruidoso, New Mexico: Socorro, New Mexico Bureau of Mines and Mineral Resources, p. 37–47.

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

Rawson, D. E., 1957, The geology of the Tecolote Hills area, Lincoln County, New Mexico [M.S. thesis]: Albuquerque, University of New Mexico, 77 p.

Reiche, P., 1949, Geology of the Manzanita and north Manzano Mountains, New Mexico: Geological Society of America Bulletin, v. 60, p. 1183–1212.

Ryberg, G. E., 1968, The geology of the Jicarilla Mountains, Lincoln County, New Mexico [M.S. thesis]: Albuquerque, University of New Mexico, 95 p.

Smith, C. T., 1964, Geology of the Little Black Peak quadrangle, Lincoln and Socorro Counties, New Mexico: New Mexico Geological Society, Guidebook 15, p. 92–99.

Smith, C. T., Osburn, G. R., Chapin, C. E., Hawley, J. W., Osburn, J. C., Anderson, O. J., Rosen, S. D., Eggleston, T. L. and Cather, S. M., 1983, First day road log from Socorro to Mesa del Yeso, Joyita Hills, Johnson Hill, Cerros de Amado, Lomas de las Canas, Jornada del Muerto, Carthage, and return to Socorro: New Mexico Geological Society, Guidebook 34, p. 1–28.

Stewart, J. H., Poole, F. G. and Wilson, R. F., 1972a, 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.

Weber, R. H., 1964, Geology of the Carrizozo quadrangle, New Mexico: New Mexico Geological Society, Guidebook 15, p. 100–109.

Wilpolt, R. H. and Wanek, A. A., 1951, Geology of the region from Socorro and San Antonio east to Chupadera Mesa, Socorro County, New Mexico: U.S. Geological Survey, Oil and Gas Investigations Map OM-121.

Woodward, L. A., 1977, Rate of crustal extension across the Rio Grande rift near Albuquerque, New Mexico: Geology, v. 5, p. 269–272.

APPENDIX—MEASURED STRATIGRAPHIC SECTIONS

The numbered, lithologic units in the measured sections in Figs. 3–4 are described here. Colors are those of Goddard et al. (1984).

Carrizo Arroyo

Measured in the N1/2 NE1/4 NE1/4 sec. 7, T6N, R2W, Valencia County. Strata dip 31° to N83°E.

unit	lithology	thickness (m)
	San Pedro Arroyo Formation:	
	Ojo Huelos Member:	
20	Limestone; yellowish gray (5 Y 7/2); micritic; somewhat nodular.	0.4+
19	Mudstone; dusky blue (5 PB 3/2) and grayish purple (5 P 4/2) with yellowish gray (5 Y 8/1) mottles; bentonitic; calcareous.	3.6
18	Limestone; mottled dusky blue (5 PB 3/2), white (N9) and light bluish gray (5 B 7/1); nodular.	1.8
17	Limestone; very pale orange (10 YR 8/2); coarsely recrystallized and dolomitic in places; nodular; a few quartzite pebbles.	1.0
	lower member:	
16	Sandy siltstone; very dusky red purple (5 RP 2/2) with very pale orange (10 YR 8/2) mottles; not calcareous.	0.9
	mottled strata:	
15	Silty sandstone and conglomerate; same colors and lithology as unit 1 of Ojo Huelos section.	0.8
	unconformity	
	Moenkopi Formation:	
	Anton Chico Member:	
14	Mudstone; grayish red (5 R 4/2); micaceous; not calcareous.	0.5
13	Sandy mudstone; grayish red (10 R 4/2) and light olive gray (5 Y 6/1); calcareous; 2.5 m above base of unit is 0.5-m-thick bed of laminar sandstone of unit 12 lithology; unit is partially covered.	14.5
12	Sandstone; grayish red (5 R 4/2); very fine-fine grained; moderately sorted; subrounded; micaceous litharenite; calcareous; nodular.	0.6
11	Siltstone; same color and lithology as unit 7.	1.1
10	Sandstone; pale red (5 R 6/2) and pale brown (5 YR 5/2); fine-medium grained; moderately sorted; subrounded; micaceous litharenite; calcareous; trough crossbedded.	2.1
9	Siltstone; same color and lithology as unit 7.	3.8
8	Sandstone and siltstone; sandstone is grayish red (10 R 4/2); very fine-fine grained; moderately sorted; subrounded; calcareous; micaceous litharenite; siltstone is same color and lithology as unit 7; laminar and ripple-laminar sandstone thinly interbedded with siltstone.	6.8
7	Siltstone; grayish red (10 R 4/2); micaceous; calcareous; some thin sandy lenses.	4.7
6	Sandstone; greenish gray (5 GY 6/1); very fine grained; well sorted; subrounded; calcareous; micaceous litharenite; laminar and ripple laminar.	0.7
5	Mudstone; light greenish gray (5 GY 8/1); calcareous; somewhat laminar.	4.3
4	Sandstone; pale olive (10 Y 6/2) and yellowish gray (5 Y 7/2); very fine-medium grained; poorly sorted; subrounded-subangular; micaceous litharenite; calcareous; laminar to ripple laminar.	2.5
3	Sandy siltstone; grayish yellow green (5 GY 7/2) and pale greenish yellow (10 Y 8/2); not calcareous; top third is muddy and calcareous.	1.4
2	Conglomerate; pale olive (10 Y 6/2) to light olive gray (5 Y 5/2); clasts are San Andres limestone pebbles up to 0.5 cm in diameter.	0.5
	unconformity	
	San Andres Formation:	
1	Limestone; light olive gray (5 Y 5/2); micritic; slightly laminar.	not measured

Ojo Huelos

Measured at approximately 34°34′46″N, 106°46′42″W, Valencia County. Strata dip 16° to N82°E.

unit	lithology	thickness (m)
San Pedro Arroyo Formation:		
Ojo Huelos Member (type section):		
7	Limestone; dusky yellow (5 Y 6/4) and light gray (N7); weathering rind is yellowish gray (5 Y 7/2); pisolitic.	0.5+
6	Sandy mudstone; yellowish gray (5 Y 7/2); contains thin limestone ledges of unit 7 lithology, NMMNH locality 354 in upper 0.3 m.	1.3
5	Limestone; medium gray (N5); micritic.	0.4
4	Sandy mudstone; dark yellowish orange (10 YR 6/6) and yellowish gray (5 Y 7/2); contains some nodules of micritic limestone.	3.9
3	Limestone; mottled dark yellowish orange (10 YR 6/6), moderate yellowish brown (10 YR 5/4) and dusky yellowish brown (10 YR 2/2); pisolitic; basal 0.5 m has fenestrate texture and is heavily recrystallized in places.	1.3
lower member:		
2	Sandy mudstone; very dusky red purple (5 RP 2/2); calcareous.	0.9
mottled strata:		
1	Silty sandstone and conglomerate; sandstone is mottled grayish red (5 R 4/2), pale yellowish orange (10 YR 8/6) and pinkish gray (5 YR 8/1); it is fine grained, poorly sorted, subangular-angular, calcareous, quartzarenite; pebbles are red, orange and gray jasper and chert as much as 5 cm in diameter; parts of unit are clayey and trough crossbedded.	4.6+

Sevilleta Grant

Measured in the SE¼ NW¼ SE¼ sec. 22 (unsurveyed), T1N, R2E, Socorro County. Strata dip 32° to S72°E.

unit	lithology	thickness (m)
fault		
San Pedro Arroyo Formation:		
upper part:		
26	Limestone; light olive gray (5 Y 5/2); nodular calcrete.	0.3
25	Mudstone; same colors and lithology as unit 21.	3.3
Ojo Huelos Member:		
24	Limestone; mottled pinkish gray (5 R 8/1), very pale orange (10 YR 8/2), grayish pink (5 R 8/2) and grayish orange pink (10 R 8/2); micritic to nodular; top half of unit contains much nodular chert and is fossiliferous (NMMNH locality 1330).	1.5
23	Mudstone; same colors and lithology as unit 21.	1.2
22	Limestone; light gray (N7); micritic; some stylolites.	0.5
21	Mudstone; variegated and mottled dusky blue (5 PB 3/2), dusky yellow (5 Y 6/4), light olive brown (5 Y 5/6) and grayish red (5 R 4/2); bentonitic.	25.6
mottled strata:		
20	Siltstone; mottled grayish red (5 R 4/2), grayish orange pink (10 R 8/2), grayish pink (5 R 8/2) and pale red (5 R 6/2); some parts are muddy; has extensive nodular calcrete.	5.0
unconformity		
Moenkopi Formation:		
Anton Chico Member:		
19	Sandstone; lower part is same colors and lithology as unit 12; upper part is grayish red (5 R 4/2 and 10 R 4/2), calcareous silty sandstone.	4.8
18	Sandstone; and conglomerate; grayish red (5 R 4/2 and 10 R 4/2); sandstone is fine-medium grained, poorly sorted, subangular, lithic graywacke; conglomerate has pebble-site clasts of limestone, siltstone and sandstone; trough crossbedded.	9.8
17	Mudstone; same colors and lithology as unit 13 but with 0.6-m-thick sandstone lens at top.	5.8
16	Sandstone; same colors and lithology as unit 12; some conglomerate lenses like conglomerate of unit 18.	1.4
15	Mudstone; same color and lithology as unit 13.	4.9
14	Sandstone; same colors and lithology as unit 12.	3.0
13	Silty mudstone; pale reddish brown (10 R 5/4); calcareous.	5.1
12	Sandstone; pale red (5 R 6/2) and grayish red (5 R 4/2); medium grained; moderately sorted; subangular; lithic graywacke; trough crossbedded.	1.2
11	Silty mudstone; grayish red (10 R 4/2); slightly calcareous.	3.1
10	Sandstone and conglomerate; sandstone is same colors and lithology as unit 6.	0.8
9	Sandy/silty mudstone; same colors and lithology as unit 5.	4.8
8	Sandstone; same colors and lithology as unit 6.	1.3
7	Sandy/silty mudstone; same colors and lithology as unit 5.	5.5
6	Sandstone; light olive gray (5 Y 6/1) to light bluish gray (5 B 7/1) with brownish gray (5 YR 4/1) weathering rind; fine-grained; moderately sorted; subangular; lithic graywacke; calcareous; trough crossbedded.	1.1
5	Sandy/silty mudstone; grayish red (10 R 4/2); contains some light olive gray (5 Y 6/1) silty sandstone lenses.	2.4
4	Sandstone; pale red (5 R 6/2); weathers to grayish red (5 R 4/2); fine grained; moderately sorted; subangular; lithic graywacke; trough crossbedded.	6.2
unconformity		
Artesia Formation:		
3	Siltstone; dark reddish brown (10 R 3/4) to moderate reddish brown (10 R 4/6); calcareous; contains pale reddish brown (10 R 5/4) 0.1-m-thick calcarenite bed near base and some thin, laminar, very fine-grained sandstone layers which are light greenish gray (5 GY 8/1) and quartzose.	2.1
2	Sandy siltstone; grayish orange pink (10 R 8/2), pale red (10 R 6/2) and grayish pink (5 R 8/2); weathers moderate pink (5 R 7/4) and pinkish gray (5 R 8/1); very calcareous; ripple laminar.	0.3
1	Siltstone; moderate reddish brown (10 R 4/6); weathers grayish red (10 R 4/2) and dark reddish brown (10 R 3/4); calcareous; bioturbated.	1.0±

Carthage A

Measured in the NW¼ SW¼ sec. 3, T5S, R2E, Socorro County. Strata dip 20° to S62°E.

unit	lithology	thickness (m)
Moenkopi Formation:		
14	Sandstone; same colors and lithology as unit 12; contains some scour fills of siltstone-pebble conglomerate with clasts as much as 2 cm in diameter.	3.0
13	Covered; sandstone like unit 12?	4.3
12	Sandstone; pale olive (10 Y 6/2) and yellowish gray (5 Y 7/2); very fine-medium grained; poorly sorted; subangular; calcareous; micaceous litharenite; planar crossbedded; unit thickens significantly on strike to W.	0.7
11	Sandstone; grayish red (10 R 4/2) to moderate brown (5 YR 3/4); very fine-medium grained; poorly sorted; subangular; not calcareous; micaceous graywacke; ripple laminar.	10.7
10	Mudstone and conglomerate; mudstone is pale red (5 R 6/2) to grayish red (10 R 4/2) and slightly calcareous; basal 0.2 m is conglomerate with sandstone matrix like unit 11 and grayish red (10 R 4/2) siltstone pebbles as much as 0.5 cm in diameter.	1.4
unconformity		
Artesia Formation:		
9	Sandstone; light greenish gray (5 GY 8/1) and yellowish gray (5 Y 8/1); very fine grained, well sorted; subrounded; quartzarenite; calcareous; a few micas; massive.	1.9
8	Siltstone; grayish orange (10 YR 7/4) and light olive gray (5 Y 6/1); calcareous; gypsiferous.	1.4
7	Sandstone; grayish orange (10 YR 7/4) and pale yellowish orange (10 YR 8/6); very fine-fine grained; well sorted; subrounded; quartzarenite; some micas; massive.	0.3

6	Siltstone; very pale orange (10 YR 8/2) and pale yellowish orange (10 YR 8/6); not calcareous.	1.3
5	Sandy siltstone; light greenish gray (5 GY 8/1); calcareous; sand grains are mostly quartz and a few micas.	0.3
4	Sandstone; light greenish gray (5 GY 8/1); very fine-fine grained; moderately sorted; calcareous; quartzarenite; some micas; massive to laminar.	1.5
3	Sandstone; pale olive (10 Y 6/2) and moderate reddish brown (10 R 4/6); very fine grained; well sorted; subrounded; quartzarenite; slightly calcareous; massive.	1.0
2	Sandy siltstone; moderate reddish orange (10 R 6/6) and pale reddish brown (10 R 5/4) with pale greenish yellow (10 Y 8/2) mottles; calcareous; slope.	4.0
	San Andres Formation:	
1	Limestone; yellowish gray (5 Y 8/1) and light olive gray (5 Y 6/1); micrite; partly dolomitic.	not measured

Carthage B

Measured in the NE1/4 NE1/4 sec. 8, T5S, R2E, Socorro County. Strata are flat-lying.

unit	lithology	thickness (m)
	Shinarump Formation:	
3	Sandstone and conglomerate; sandstone is pale yellowish brown (10 YR 6/2) and light olive gray (5 Y 5/2), very fine-fine grained, moderately sorted, subrounded, not calcareous, feldspathic litharenite; conglomerate consists of gray, black, white and pink quartzite and chert clasts as much as 3 cm in diameter; planar crossbedded.	1.9+
	unconformity	
	Moenkopi Formation (Anton Chico Member):	
2	Silty sandstone; same color and lithology as unit 1; ripple laminar.	1.4
1	Sandstone; grayish red (5 R 4/2); very fine-fine grained; moderately sorted; subrounded; slightly calcareous; micaceous litharenite; laminar.	0.9+

Carthage D

Measured in the SE1/4 SE1/4 sec. 4, T5S, R2E, Socorro County, New Mexico. Strata dip 17° to S3°W.

unit	lithology	thickness (m)
	San Pedro Arroyo Formation:	
5	Sandstone; grayish red (5 R 4/2); very fine-fine grained; moderately sorted; subrounded-subangular; micaceous litharenite; slightly calcareous; laminar.	2.0+
	Shinarump Formation:	
4	Conglomeratic sandstone; matrix is pale yellowish brown (10 YR 6/2) and grayish brown (5 YR 3/2), fine-medium grained, poorly sorted, subangular-subrounded; micaceous; not calcareous; subarkose; pebbles are gray, black and orange hued quartzite and chert up to 4 cm in diameter; trough crossbedded.	4.6
	unconformity	
	Moenkopi Formation:	
	Anton Chico Member:	
3	Sandstone and conglomerate; sandstone is grayish red (10 R 4/2), very fine-fine grained, moderately sorted, subrounded-subangular, calcareous, micaceous litharenite; conglomerate occurs as thin, scour-fill lenses of pale red (5 R 6/2) siltstone and limestone pebbles as much as 2 cm in diameter; trough crossbedded.	4.2
2	Sandy siltstone; pale red (5 R 6/2) with pale greenish yellow (10 Y 8/2) mottles; calcareous; rudely laminar.	0.9
1	Sandstone; pale red (5 R 6/2) and grayish red (10 R 4/2); fine grained, well sorted; subrounded; micaceous litharenite; slightly calcareous; trough crossbedded.	2.0+

Carthage E

Measured in the SE1/4 SE1/4 sec. 5, T5S, R2E, Socorro County. Strata dip 18° to S55°W.

unit	lithology	thickness (m)
	San Pedro Arroyo Formation:	
8	Siltstone; grayish yellow green (5 GY 7/2); contains nodular masses of gray to black goethite as much as 15 cm in diameter; not calcareous; unit grades upward into bluish mudstones.	2.0+
	Ojo Huelos Member:	
7	Limestone; dark yellowish brown (10 YR 4/2) and moderate yellowish brown (10 YR 5/4); pisolitic; contains some masses of dusky yellowish green (5 GY 5/2), calcareous siltstone; forms a ledge.	3.9
	lower member:	
6	Siltstone; grayish red (5 R 4/2) and pale green (5 G 7/2); not calcareous; laminar to massive; contains some sandstone lenses that are light greenish gray (5 G 8/1), very fine-fine grained, poorly sorted, subangular, micaceous litharenite; forms a slope.	3.8
5	Conglomerate; light olive gray (5 Y 5/2) and pale olive (10 Y 6/2); composed mostly of pale red (5 R 6/2), calcareous siltstone pebbles up to 1.5 cm in diameter; matrix is fine-coarse grained, poorly sorted, subangular micaceous quartzarenite; contains bone fragments and coprolites.	1.4
4	Sandstone, siltstone and conglomerate in thin interbeds; sandstone is grayish red (5 R 4/2), very fine grained, well sorted, subangular, micaceous, calcareous, trough-crossbedded litharenite; siltstone is grayish red (10 R 4/2) to pale reddish brown (10 R 5/4) and calcareous; conglomerate is same colors and lithology as unit 5.	2.9
3	Sandstone; light olive gray (5 Y 6/1) and greenish gray (5 GY 6/1); very fine-medium grained; poorly sorted; subrounded; micaceous subarkose; not calcareous; trough crossbedded.	2.0
	Shinarump Formation:	
2	Conglomeratic sandstone; same colors and lithology as unit 4 of Carthage D section; forms a cliff.	5.5
	unconformity (Tr-3 unconformity)	
	Moenkopi Formation:	
	Anton Chico Member:	
1	Sandstone; grayish red (5 R 4/2); very fine grained; well sorted; subrounded; micaceous litharenite; slightly calcareous; trough crossbedded.	1.0+

San Pedro Arroyo

Measured in the SE1/4 SE1/4 sec. 5 and NW1/4 NW1/4 sec. 9, T5S, R2E, Socorro County. Strata dip 25° to S50°W.

unit	lithology	thickness (m)
	Dakota Group:	
20	Sandstone; very pale orange (10 YR 8/2) with dusky brown (5 YR 2/2) weathering rind; medium grained; well sorted; subrounded; quartzarenite; trough crossbedded.	not measured
	unconformity	
	Morrison Formation:	
19	Sandstone and claystone; sandstone is very pale orange (10 YR 8/2), fine grained, well sorted, subrounded, calcareous, kaolinitic, laminar, subarkose; claystone is moderate red (5 R 5/4 and 5 R 4/6) and calcareous.	4.0
	unconformity	
	San Pedro Arroyo Formation (type section):	
18	Sandstone; grayish red (5 R 4/2) and blackish red (5 R 2/2); very fine-fine grained; poorly sorted; subangular; micaceous litharenite; ripple laminar.	2.0
17	Sandstone; same colors and lithology as unit 15.	1.8
16	Sandstone, mudstone and conglomerate; sandstone is same	

	colors and lithology as unit 15; mudstone is grayish red (5 R 4/2) and calcareous; conglomerate has clasts that are brownish gray (5 YR 4/1) and grayish red (5 R 4/2) limestone pebbles up to 8 mm in diameter; trough crossbedded sandstone/conglomerate intercalated with 0.3-m-thick mudstone beds.	6.5
15	Sandstone; grayish purple (5 P 4/2) and grayish red (5 R 4/2); very fine-fine grained; poorly sorted; subangular; not calcareous; micaceous litharenite; trough crossbedded.	1.0
14	Mudstone; grayish red (5 R 4/2) and light greenish gray (5 GY 8/1); calcareous; bentonitic; contains light greenish gray calcrete nodules as much as 3.5 cm in diameter.	22.5
13	Sandstone and muddy siltstone; sandstone is grayish red (5 R 4/2), very fine grained, well sorted, subangular, silty, not calcareous, trough crossbedded, micaceous litharenite; siltstone is grayish red (10 R 4/2), not calcareous and extensively interbedded with sandstone.	3.0
12	Sandstone and conglomerate; sandstone is grayish red (5 R 4/2) and very dusky red (10 R 2/2); very fine-medium grained; poorly sorted; subangular; calcareous, laminar litharenite; conglomerate contains clasts of grayish red (10 R 4/2), not calcareous mudstone up to 1 cm in diameter.	2.8
11	Mudstone; grayish red (10 R 4/2), dark reddish brown (10 R 3/4) and very pale orange (10 YR 8/2); some calcrete nodules.	18.0
10	Sandstone and conglomerate; sandstone is medium light gray (N6) and blackish red (5 R 2/1), very fine grained, well sorted, subangular, quartzose but with a few micas and feldspars and metamorphosed to a very hard orthoquartzite; conglomerate is same colors and lithology as unit 8; trough crossbedded; NMMNH locality 589.	10.0
9	Mudstone; grayish red (10 R 4/2); bentonitic; slightly calcareous; contains some lenses of conglomerate of unit 8 lithology and sandstone that are grayish red (5 R 4/2) and blackish red (5 R 2/2), very fine-fine grained, poorly sorted, subangular, trough-crossbedded litharenite.	12.0
8	Conglomerate; mottled grayish olive green (5 GY 3/2) and grayish red (5 R 4/2); clasts are limestone and mudstone pebbles up to 1.5 cm in diameter; forms a persistent ledge; NMMNH locality 590.	0.8
7	Mudstone; dusky red (5 R 3/4); calcareous; bentonitic; contains light bluish gray (5 B 7/1) calcrete nodules up to 8 cm in diameter.	30.3
Ojo Huelos Member:		
6	Limestone; mottled grayish olive (10 Y 4/2) and olive gray (5 Y 3/2) with light olive gray (5 Y 5/2) weathering rind; pisolitic and some portions are limestone-pebble conglomerate.	1.6
lower member:		
5	Siltstone; pale brown (5 YR 5/2) and blackish red (5 R 2/2); not calcareous.	2.1
4	Sandstone; pale brown (5 YR 5/2) and grayish red (5 R 4/2); fine grained; well sorted; subrounded; not calcareous; litharenite; small trough crossbedded and ripple laminar.	2.0
3	Nodular limestone; mottled grayish red purple (5 RP 4/2) and pale yellowish orange (10 YR 8/6); nodules are micritic and up to 6 cm in diameter.	0.3
2	Sandy siltstone; grayish red (10 R 4/2) and pale reddish brown (10 R 5/4); slightly calcareous; some portions are sandy and/or muddy; ripple laminar.	6.0
Shinarump Formation:		
1	Sandstone and conglomerate; sandstone is pale brown (5 YR 5/2) and pale red (5 R 6/2), fine-medium grained, moderately sorted, subrounded-subangular, not calcareous, micaceous quartzarenite; conglomerate clasts are gray, black and pink quartzite and chert up to 3 cm in diameter; trough crossbedded.	1.0+

Post Corral Tank

Measured in the NE1/4 NW1/4 NE1/4 sec. 36, T5S, R10E, Lincoln County. Strata of units 7–11 dip 30° to S60°E; units 1–6 are essentially flat-lying.

unit	lithology	thickness (m)
Dakota Group:		
Mesa Rica Sandstone:		
11	Sandstone; very pale orange (10 YR 8/2) and dark yellowish orange (10 YR 6/6); very coarse grained; well sorted; subrounded; quartzarenite; slightly calcareous; trough crossbedded and bioturbated.	1.2+
10	Sandstone; moderate yellowish brown (10 YR 5/4) to dark yellowish orange (10 YR 6/6); weathering rind is dusky yellowish brown (10 YR 2/2); very fine-fine grained; moderately sorted; subangular; slightly calcareous; quartzarenite; laminar and trough crossbedded.	1.2
unconformity		
San Pedro Arroyo Formation:		
9	Mudstone; same colors and lithology as unit 5; much covered.	5.5
8	Sandstone; grayish red (10 R 4/2); very fine-fine grained; poorly sorted; subangular; calcareous; micaceous litharenite; planar crossbedded and laminar.	2.0
7	Mudstone; same colors and lithology as unit 5; much covered.	3.7
(fault)		
6	Sandstone; grayish red (5 R 4/2) to blackish red (5 R 2/2); very fine-fine grained; moderately sorted; subrounded; not calcareous; micaceous litharenite; ripple laminar.	0.8
5	Mudstone; dark reddish brown (10 R 3/4) and pale olive (10 Y 6/2); bentonitic, calcareous; contains numerous yellowish gray (5 Y 7/2) and grayish red (5 R 4/2) calcrete nodules up to 3 cm in diameter; slope.	8.3
4	Sandstone; same colors and lithology as unit 3; lenticular trough crossbeds and persistent laminar beds; much covered.	3.0
3	Sandstone; grayish red (10 R 4/2) and grayish green (10 GY 5/2); very fine-fine grained; moderately sorted; subangular-subrounded; micaceous litharenite; slightly calcareous; planar crossbedded and laminar.	2.8
2	Sandstone and conglomerate; sandstone is pale red (5 R 6/2) and grayish red (10 R 4/2), very fine grained, well sorted, subrounded, slightly calcareous, micaceous litharenite; conglomerate has clasts of grayish orange pink (10 R 8/2) and grayish red (10 R 4/2) limestone up to 0.5 cm in diameter and brownish gray (5 YR 4/1) sandstone matrix of same lithology as rest of unit; trough crossbedded; has fragments of bone and poorly preserved unionid shells.	0.8
1	Muddy sandstone; grayish red (5 R 4/2); very fine-medium grained; poorly sorted; subangular; slightly calcareous; micaceous litharenite.	not measured

Red Hill

Measured in the SW1/4 NE1/4 sec. 1, T4S, R11E, Lincoln County. Strata dip 13° due E.

unit	lithology	thickness (m)
Santa Rosa Formation:		
11	Sandstone; very pale orange (10 YR 8/2) with dark yellowish orange (10 YR 6/6) splotches; medium-coarse grained; moderately sorted; subangular-subrounded; micaceous quartzarenite; calcareous; trough crossbedded; trough axes dip N.	3.8+
10	Sandstone; light olive gray (5 Y 6/1); fine grained; well sorted; subrounded; subarkose; laminar and trough crossbedded; some cover.	6.0
9	Conglomerate; matrix is grayish orange (10 YR 7/4) to dark yellowish orange (10 YR 6/6), very fine-fine grained, moderately sorted, subrounded, calcareous, micaceous subarkose; clasts are mostly gray and black pebbles of quarzite and chert as much as 1.0 cm in diameter; trough crossbedded.	3.2
unconformity		
Moenkopi Formation:		
Anton Chico Member:		
8	Conglomerate; matrix is grayish red (5 R 4/2), fine-medium grained, poorly sorted, subangular, calcareous, micaceous litharenite; clasts are pale red (10 R 6/2), calcareous siltstone pebbles up to 0.5 cm in diameter; trough crossbedded; contains some bone fragments.	0.6
7	Sandstone; light brownish gray (5 YR 6/1) to light olive gray (5 Y 6/1); very fine grained; well sorted; subrounded; calcareous; micaceous litharenite; planar crossbeds.	1.2
6	Mudstone; grayish red (10 R 4/2); micaceous; calcareous; much covered; has some lenses of light olive gray (5 Y 6/	

unit	lithology	thickness (m)
	1), very fine-fine grained, poorly sorted, subangular, micaceous litharenite.	10.6
5	Sandstone; grayish red (10 R 4/2) and very dusky red (10 R 2/2); very fine-fine grained; moderately sorted; subrounded-subangular; calcareous; micaceous graywacke; trough crossbedded.	13.5
4	Conglomerate; same colors and lithology as conglomerate in unit 3; trough crossbedded.	0.8
3	Sandstone and conglomerate; sandstone is grayish red (10 R 4/2), very fine-fine grained, moderately sorted, subrounded, not calcareous, micaceous litharenite; conglomerate has clasts of orange limestone pebbles up to 1 cm in diameter.	0.4
	unconformity	
	Artesia Formation:	
2	Sandy and clayey siltstone; grayish red (10 R 4/2) with grayish green (10 GY 5/2) and pale olive (10 Y 6/2) clayey patches; calcareous.	0.3
1	Sandy siltstone; grayish red (10 R 4/2) with light greenish gray (5 GY 8/1) mottles; not calcareous; a few micas; thin bedded: laminar and ripple laminar; some beds are bioturbated.	not measured

Round Tank

Measured in the SE1/4 NW1/4 SE1/4 sec. 34, T5S, R11E, Lincoln County. Strata dip 20° to N30°E.

unit	lithology	thickness (m)
	Dakota Group:	
	Mesa Rica Sandstone:	
11	Sandstone; grayish orange (10 YR 7/4) and dark yellowish orange (10 YR 6/6); medium-coarse grained; moderately sorted; subrounded; calcareous; quartzarenite; trough and planar crossbedded; some overturned crossbeds and bioturbation.	not measured
	unconformity	
	San Pedro Arroyo Formation:	
10	Mudstone; moderate reddish brown (10 R 4/6) to grayish red (10 R 4/2); bentonitic; calcareous; some calcrete nodules as much as 2 cm in diameter; contains some platey ledges of grayish red (10 R 4/2), fine grained, well sorted, subrounded, slightly calcareous, laminar, micaceous litharenite; much covered.	15.3
9	Sandstone; grayish red (10 R 4/2); very fine-fine grained; well sorted; subangular-subrounded; micaceous litharenite; slightly calcareous; through crossbedded.	1.6
8	Silty sandstone; moderate reddish brown (10 R 4/6); very fine grained; well sorted; subrounded; litharenite; calcareous; laminar and ripple laminar in small troughs.	2.3
7	Sandstone and conglomerate; sandstone is grayish red (10 R 4/2) and moderate reddish brown (10 R 4/6), very fine-fine grained, well sorted, subrounded, calcareous litharenite; conglomerate clasts are olive gray (5 Y 4/1) and dark greenish gray (5 GY 4/4) limestone and calcareous siltstone pebbles up to 8 cm in diameter; trough crossbedded; trough axes dip to N/NE; some bone fragments and coprolites.	2.2
6	Mudstone; dusky red (5 R 3/4) with pale greenish yellow (10 Y 8/2) mottles; bentonitic; calcareous; contains calcrete nodules up to 2 cm in diameter.	10.8
5	Mudstone; same colors and lithology as unit 3.	24.6
4	Conglomerate; brownish gray (5 YR 4/1) and olive gray (5 Y 4/1); clasts are limestone pebbles up to 0.5 cm in diameter; NMMNH locality 591; also contains some goethite nodules as much as 0.5 cm in diameter; unit is lenticular over 30 m of strike.	1.5
3	Mudstone; grayish purple (5 P 4/2) and very dusky purple (5 P 2/2); bentonitic; calcareous; contains many calcrete nodules up to 6 cm in diameter, especially concentrated in 0.1–0.3-m-thick layers every 1–1.5 m.	19.0
2	Sandstone; medium bluish gray (5 B 5/1) and medium gray (N5) with speckles of dark yellowish orange (10 YR 6/6); fine-medium grained; poorly sorted; subangular; calcareous; micaceous litharenite; laminar.	1.6
	Santa Rosa Formation:	
1	Sandstone; speckled grayish orange (10 YR 7/4) and dark yellowish orange (10 YR 6/6) with a dark yellowish brown (10 YR 4/2) weathering rind; fine grained, well sorted, subrounded, calcareous quartzarenite; planar and trough crossbedded.	not measured

Ancho

Measured in the NW1/4 SW1/4 SW1/4 sec. 22, T4S, R11E, Lincoln County. Strata dip 8° to S10°W.

unit	lithology	thickness (m)
	Santa Rosa Formation:	
15	Conglomerate; same lithology as unit 14; grayish red (5 R 4/2); calcareous; clasts as much as 3 cm in diameter.	1.5+
14	Conglomerate; matrix is grayish red (10 R 4/2), very fine-medium grained, poorly sorted, subrounded, not calcareous, micaceous litharenite; clasts are black, gray, white and yellowish orange quartzite and chert up to 8 cm in diameter; some trough crossbedding.	0.3–0.6
	unconformity	
	Moenkopi Formation:	
	Anton Chico Member:	
13	Sandstone; grayish red (5 R 4/2); very fine-fine grained; well sorted; subrounded; mcaceous litharenite; slightly calcareous; trough crossbedded.	1.4
12	Sandstone; grayish red (10 R 4/2) and pale green (5 G 7/2); very fine-medium grained; poorly sorted; subangular; slightly calcareous; micaceous litharenite; laminar and ripple laminar.	0.4
11	Muddy siltstone; grayish red (5 R 4/2); calcareous.	0.7
10	Mudstone and siltstone; same color and lithology as unit 8.	0.3
9	Sandstone; same colors and lithology as unit 7.	1.0
8	Mudstone and siltstone; grayish red (10 R 4/2); slightly calcareous; siltstone forms thin, ripple-laminar ledges.	4.6
7	Sandstone; grayish red (10 R 4/2) and greenish gray (5 GY 6/1); very fine grained; well sorted; subangular; not calcareous; micaceous litharenite; contains some mudstone pebbles of unit 6 lithology; trough crossbedded and ripple laminar.	4.3
6	Mudstone; grayish red (10 R 3/4) with pale olive (10 Y 6/2) mottles; slightly calcareous.	1.4
5	Conglomerate; matrix is pale reddish brown (10 R 5/4), medium-coarse grained, poorly sorted, subrounded, slightly calcareous, micaceous litharenite; clasts are pale greenish yellow (10 Y 8/2) mudstone; trough crossbedded.	0.3
4	Sandstone; same colors and lithology as sandstone in unit 3; trough crossbedded; contains oxidized plant debris.	2.7
3	Sandstone and siltstone; sandstone is grayish red (10 R 4/2) and pale yellowish green (10 GY 7/2), very fine grained, well sorted, subrounded, not calcareous, micaceous litharenite; ripple laminar with a few trough crossbeds; siltstone is pale olive (10 Y 6/2) and grayish red (10 R 4/2), not calcareous and clayey.	5.8
2	Sandstone; pale red (5 R 6/2) and pale greenish yellow (10 Y 8/2); very fine grained; moderately sorted: some very coarse sand grains and siltstone pebbles; subangular; micaceous litharenite; trough crossbedded.	0.5
	unconformity	
	Artesia Formation:	
1	Siltstone; moderate reddish brown (10 R 4/6); calcareous; contains thin, light gray (N8), coarsely recrystallized limestone layers; also contains some sand grains and clay pebbles.	not measured

Bull Gap N

Measured in the N1/2 SE1/4 SE1/4 sec. 14, T9S, R8E, Lincoln County. Strata dip 12° to N40°E.

unit	lithology	thickness (m)
	Dakota Group:	
	Mesa Rica Sandstone:	
35	Sandstone; very pale orange (10 YR 8/2) and pale yellowish brown (10 YR 6/2); coarse grained; well sorted; subrounded; quartzarenite; trough crossbedded; has some gray, white and black quartzite pebbles up to 2 cm in diameter.	not measured
34	Sandstone and conglomerate; same colors and lithology as unit 13 of Bull Gap section.	1.8

	unconformity	
	Moenkopi Formation:	
	Anton Chico Member:	
33	Sandy siltstone; white (N9); not calcareous.	1.3
32	Silty sandstone; same colors and lithology as unit 31; massive to laminar.	4.0
31	Sandstone; grayish red (5 R 4/2) with very pale orange (10 YR 8/2) mottling; very fine-fine grained; well sorted; subrounded; micaceous litharenite; laminar and shallow trough crossbeds.	1.8
30	Sandstone; grayish pink (5 R 8/2) and moderate orange pink (10 R 7/4); fine-medium grained; well sorted; subangular; not calcareous; micaceous litharenite; paleoweathering horizon?	1.0
29	Sandstone; same colors and lithology as sandstone in unit 28 except medium grained, micaceous litharenite; trough crossbedded.	4.5
28	Sandstone and conglomerate; sandstone is grayish red (5 R 4/2) and blackish red (5 R 2/2), medium-coarse grained, poorly sorted, subrounded, micaceous graywacke; conglomerate has clasts of gray, white and red quarzite, chert and siltstone up to 0.4 cm in diameter; trough crossbedded.	2.4
27	Silty sandstone; grayish red (10 R 4/2) and pale red (5 R 6/2), very fine grained, moderately sorted, subrounded, micaceous litharenite; laminar.	2.4
26	Sandstone; grayish red (10 R 4/2); very fine-fine grained; poorly sorted; subangular; not calcareous; micaceous litharenite; ripple laminar and laminar in shallow trough crossbeds; some flattened siltstone pebbles up to 1 cm in diameter.	2.8
25	Muddy siltstone; same lithology as unit 21 but dominant color is light greenish gray (5 GY 8/1); contains 0.1-m-thick bed of nodular calcrete 6 m above base.	13.3
24	Conglomerate; same colors and lithology as unit 22.	0.3
23	Muddy siltstone; same colors and lithology as unit 21.	5.4
22	Conglomerate; pale olive (10 Y 6/2) and grayish red (5 R 4/2); clasts are mostly calcareous siltstone and limestone up to 0.5 cm diameter, but a few black chert pebbles are present; trough crossbedded.	0.8
21	Muddy siltstone; grayish red (10 R 4/2) with yellowish gray (5 Y 7/2) mottles; calcareous; contains some 0.3–0.9-m-thick lenses of laminar sandstone that are grayish red (10 R 4/2), very fine grained, well sorted, micaceous litharenite.	3.4
20	Sandstone; grayish red (10 R 4/2) and yellowish gray (5 Y 7/2); very fine grained; well sorted; subrounded; not calcareous; micaceous litharenite; laminar and ripple laminar in shallow troughs.	0.6
19	Siltstone; pale red (5 R 6/2) and light greenish gray (5 G 8/1); calcareous; laminar and small trough crossbeds.	8.3
18	Sandstone; same colors and lithology as unit 17 but with some yellowish gray (5 Y 7/2) mottles; laminar and shallow trough crossbeds; top of unit is ripple laminar.	3.0
17	Sandstone; grayish brown (5 YR 3/2) to grayish red (5 R 4/2); very fine-fine grained; well sorted; subrounded; not calcareous; micaceous litharenite; laminar and shallow trough crossbeds.	0.9
16	Conglomerate; clasts are unit 15 rip-ups up to 0.5 cm diameter in very coarse-grained sandstone; grayish red (5 R 4/2); trough crossbedded; contains bone fragments.	0.4
15	Siltstone; grayish red (10 R 4/2) with light greenish gray (5 GY 8/1) streaks; calcareous.	3.0
14	Sandstone and conglomerate; sandstone is pale brown (5 YR 5/2) and grayish red (10 R 4/2), very fine-fine grained, poorly sorted, subrounded-subangular, slightly calcareous, micaceous graywacke; conglomerate is same sandstone matrix that is pale olive (10 Y 6/2) with pebbles of grayish red (5 R 4/2), calcareous siltstone up to 1.5 cm in diameter; trough crossbedded.	3.4
13	Sandstone and conglomerate; sandstone is grayish red (5 R 4/2) and grayish purple (5 P 4/2), medium-coarse grained, poorly sorted, subrounded, calcareous, micaceous litharenite; conglomerate is limestone pebbles up to 1.5 cm in diameter; trough crossbedded.	2.1
12	Siltstone and silty sandstone; grayish red; calcareous; sandstone is very fine-fine grained, well sorted, subrounded, laminar, micaceous litharenite.	1.8
11	Sandstone; brownish gray (5 YR 4/1) and pale red (5 R 6/2); very fine-medium grained; poorly sorted; subangular; micaceous litharenite; trough crossbedded in 0.3–0.6-m-thick sets.	4.0
10	Mudstone; same colors and lithology as unit 8; some cover.	13.0
9	Sandstone; light olive gray (5 Y 6/1) with brownish gray (5 YR 4/1) weathering rind; fine-medium grained; poorly sorted; subrounded; calcareous; micaceous litharenite; trough crossbedded; lower 0.6 m is light greenish gray (5 GY 8/1) limestone-pebble conglomerate with clasts as much as 0.5 cm in diameter.	3.0
8	Mudstone; grayish red (10 R 4/2) with pale greenish yellow (10 Y 8/2) mottles; very calcareous; some 0.3-m-thick lenses of bioturbated sandstone.	4.4
7	Sandstone; same colors and lithology as unit 6 except fine grained; shallow trough crossbedded.	5.1
6	Sandstone; grayish yellow green (5 GY 7/2) with moderate yellowish brown (10 YR 5/4) weathering rind; medium grained; well sorted; subrounded; calcareous; micaceous subarkose; trough crossbedded.	2.3
5	Conglomerate; grayish brown (5 YR 3/2) and moderate brown (5 YR 4/4); calcareous; clasts are siltstone pebbles up to 0.5 cm in diameter.	0.6
4	Sandstone; same colors and lithology as unit 3; trough crossbedded.	2.2
3	Sandstone; yellowish gray (5 Y 7/2) and pale olive (10 Y 6/2); very fine-medium grained; poorly sorted; subrounded; micaceous litharenite; contains some clay pebbles up to 1 cm in diameter; ripple laminar with some horizontal burrows.	0.3
	unconformity	
	Artesia Formation:	
2	Sandstone; pale red (10 R 6/2) and yellowish gray (5 Y 7/2); very fine grained; well sorted; subrounded; quartzarenite; a few micas; trough crossbedded and ripple laminar.	4.8
1	Gypsiferous mudstone and siltstone; moderate reddish brown (10 R 4/6) and moderate reddish orange (10 R 6/6); very calcareous; very pale orange (10 YR 8/2) thin layers and nodules of gypsum.	1.5+

Bull Gap

Measured in the NE¼ SE¼ SE¼ sec. 27, T9S, R8E, Lincoln County. Strata dip 12° to N40°E.

unit	lithology	thickness (m)
	Dakota Group:	
	Mesa Rica Sandstone:	
14	Sandstone and conglomerate; sandstone is very pale orange (10 YR 8/2) with dark yellowish orange (10 YR 6/6) hematized mottles, medium-very coarse grained; poorly sorted; subangular-subrounded; not calcareous; quartzarenite; conglomerate clasts are black and gray cherts up to 1.5 cm in diameter; trough crossbedded.	not measured
13	Sandstone and conglomerate; sandstone is liesegang banded light bluish gray (5 B 7/1), moderate reddish orange (10 R 6/6) and moderate red (5 R 5/4), very fine grained, well sorted, subrounded, laminar and trough crossbedded, not calcareous, quartzarenite; conglomerate has clasts of dark yellowish orange (10 YR 6/6) and very pale orange (10 YR 8/2) siltstone pebbles up to 3 cm in diameter; matrix is pale yellowish brown (10 YR 6/2), medium grained, well sorted, quartzarenite; this is a deeply weathered zone.	1.7
	unconformity	
	Moenkopi Formation:	
	Anton Chico Member:	
12	Silty mudstone; dark reddish brown (10 R 3/4) and dusky red (5 R 3/4); not calcareous.	5.0
11	Sandstone; grayish red (5 R 4/2 and 10 R 4/2); very fine-fine grained; moderately sorted; subangular; micaceous litharenite; calcareous; laminar with some small trough crossbeds and bioturbation.	7.5
10	Sandstone; same colors and lithology as sandstone in unit 9 except very fine-fine grained; small trough crossbeds.	1.8

9	Sandstone and conglomerate; sandstone is light bluish gray (5 B 5/1) and light olive gray (5 Y 5/2), fine-medium grained, poorly sorted, subrounded-subangular, calcareous; micaceous litharenite; conglomerate has clasts of moderate yellowish brown (10 YR 5/4), slightly calcareous siltstone up to 2 cm in diameter; trough crossbedded with thin conglomerate lenses.	1.5
8	Sandstone; pale red (5 R 6/2) and grayish red (10 R 4/2); same lithology as unit 7; laminar and climbing ripple laminar.	4.5
7	Sandstone and conglomerate; sandstone is pale brown (5 YR 5/2) and grayish red (10 R 4/2), very fine-fine grained, moderately sorted, subrounded, not calcareous, micaceous litharenite; conglomerate clasts are siltstone pebbles of unit 6 colors and lithology up to 1 cm in diameter; trough crossbedded.	3.6
6	Siltstone and muddy siltstone; grayish red (10 R 4/2) with pale greenish yellow (10 Y 8/2) mottles; calcareous.	15.6
5	Sandstone; grayish red (10 R 4/2) and light olive gray (5 Y 5/2) to yellowish gray (5 Y 7/2); very fine-fine grained; moderately sorted; subrounded; slightly calcareous; micaceous litharenite; laminar and small trough crossbeds.	6.0
4	Conglomerate; moderate brown (5 YR 4/4); clasts are siltstone and limestone pebbles up to 0.5 cm in diameter.	0.4
3	Sandstone; grayish red (10 R 4/2); very fine grained; well sorted; subrounded; not calcareous; micaceous litharenite; trough crossbedded.	1.5
2	Conglomerate; matrix is grayish red (5 R 4/2), very fine-medium grained, poorly sorted, subangular, micaceous graywacke; clasts are moderate brown (5 YR 3/4), limestone pebbles up to 4 mm in diameter; trough crossbedded.	1.0
unconformity		
Artesia Formation:		
1	Sandy siltstone and gypsiferous mudstone; siltstone is pale reddish brown (10 R 5/4) and slightly calcareous; mudstone is moderate reddish brown (10 R 4/6) and calcareous; lower part of unit has some thin (0.3 m) ledges of yellowish gray (5 Y 7/2) and light greenish gray (5 GY 8/1), calcareous siltstone pebbles upt to 0.5 cm in diameter.	11.3+

Gyp Spring

Measured in the N½ NE¼ NW¼ sec. 6, T9S, R15E, Lincoln County. Strata dip 10° to N40°W.

unit	lithology	thickness (m)
Santa Rosa Formation:		
4	Conglomerate; same colors and lithology as unit 5 of Fort Stanton section.	1.0+
3	Sandstone and conglomerate; sandstone is grayish orange (10 YR 7/4) and dark yellowish orange (10 YR 6/6), very fine-fine grained, well sorted, subrounded, calcareous, micaceous subarkose; conglomerate matrix is pale yellowish brown (10 YR 6/2) and very pale orange (10 YR 8/2), very fine-fine grained, poorly sorted, subangular-subrounded, micaceous subarkose; clasts are mostly pale yellowish orange (10 YR 8/6) limestone up to 0.5 cm in diameter, but a few are limestone and gray/black chert and quartzite pebbles as much as 1.5 cm in diameter.	7.5
unconformity		
Artesia Formation:		
2	Gypsiferous mudstone and sandstone; mudstone is ame colors and lithology as unit 1; sandstone is yellowish gray (5 Y 7/2) and light greenish gray (5 GY 8/1), very fine-fine grained, well sorted, subroudned, not calcareous, laminar and bioturbated quartzarenite.	3.0
1	Gypsiferous mudstone; pale olive (10 Y 6/2) and yellowish gray (5 Y 7/2); calcareous.	not measured

Fort Stanton

Measured in the SW¼ SW¼ NW¼ sec. 17, T9S, R15E, Lincoln County. Strata dip 12° to N40°W.

unit	lithology	thickness (m)
Santa Rosa Formation:		
5	Conglomerate; matrix is same lithology as unit 4 and dark yellowish orange (10 YR 6/6) and brownish black (5 YR 2/1); clasts are gray, black and pink quartzite and chert as much as 2 cm in diameter.	3.0+
4	Sandstone; moderate yellowish brown (10 YR 5/4) and grayish orange (10 YR 7/4) with dusky yellowish brown (10 YR 2/2) biotite flecks; same lithology as unit 3; planar crossbedded.	0.8
3	Sandstone; grayish orange (10 YR 7/4) with speckles of dark yellowish orange (10 YR 6/6) and dusky yellowish brown (10 YR 2/2); very fine-fine grained; moderately sorted; subrounded; micaceous subarkose; very calcareous; trough crossbedded.	4.0
2	Sandy mudstone; grayish yellow (5 Y 8/4); some thin beds of laminar, bioturbated, sandy siltstone; forms a slope.	11.0
1	Sandstone and conglomerate; sandstone is grayish orange (10 YR 7/4) with speckles of dark yellowish orange (10 YR 6/6) and dusky yellowish brown (10 YR 2/2), fine grained, moderately sorted, subrounded, very calcareous, micaceous litharenite; conglomerate has matrix of medium-coarse grained, poorly sorted, subrounded, calcareous micaceous subarkose and clasts of pale yellowish orange (10 YR 8/6) limestone up to 0.5 cm in diameter; trough crossbedded; unit is much covered.	6.7+

Discussion at Day 3, Stop 5 of the Porvenir Formation by Elmer Baltz, to whom the 1990 NMGS Fall Field Conference was dedicated. Elmer briefly came out of retirement to lead the group through the southern Sangre de Cristo Mountains. Illustration by Louann Jordan of Santa Fe, 1990.