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# TRIASSIC STRATA AT CARRIZO ARROYO, LUCERO UPLIFT, CENTRAL NEW MEXICO

SPENCER G. LUCAS, ANDREW B. HECKERT AND ADRIAN P. HUNT

New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104

**Abstract**—Triassic strata exposed at Carrizo Arroyo in the Lucero uplift of central New Mexico are assigned to the Middle Triassic Anton Chico Member of the Moenkopi Formation and the Upper Triassic Chinle Group (Zuni Mountains Formation and lower part of the San Pedro Arroyo Formation, including the Ojo Huelos Member). The Ojo Huelos Member of south-central New Mexico and the lower part of the Bluewater Creek Formation in west-central New Mexico represent an extensive lacustrine-palustrine depositional system that developed during early (Adamanian) deposition of part of the lower Chinle Group.

**Key words:** Carrizo Arroyo, Lucero uplift, Chinle Group, Moenkopi Formation, Triassic, Ojo Huelos Member

## INTRODUCTION

Triassic strata are widely exposed across much of northern New Mexico and are assigned to the Moenkopi Formation of Middle Triassic age and to the Upper Triassic Chinle Group (Lucas, 1995; Lucas et al., 1999). The presence of Triassic outcrops in the Lucero uplift and at Carrizo Arroyo in particular (Fig. 1) was first recognized by Darton (1928). Subsequent workers (Kelley and Wood, 1946; Dane and Bachman, 1965; Zilinski, 1976; Callender and Zilinski, 1976) mapped these strata as Chinle Formation. Lucas and Hayden (1989), however, concluded that part of the Triassic section exposed at Carrizo Arroyo is Moenkopi Formation (also see Lucas and Heckert, 1994; Heckert, 1997; Heckert and Lucas, 1997). Here, we describe the Triassic section at Carrizo Arroyo and briefly discuss the depositional significance of the Ojo Huelos Member of the San Pedro Arroyo Formation.

## LOCATION

Triassic strata crop out east of Carrizo Mesa, principally just north and south of Carrizo Arroyo in sections 6 and 7, T6N, R2W, Valencia County (Fig. 1). These strata (Fig. 2) are east-dipping red beds that directly and disconformably overlie the Permian San Andres Formation to the west and are fault bounded by Neogene strata of the Santa Fe Group to the east (Figs. 3A-B).

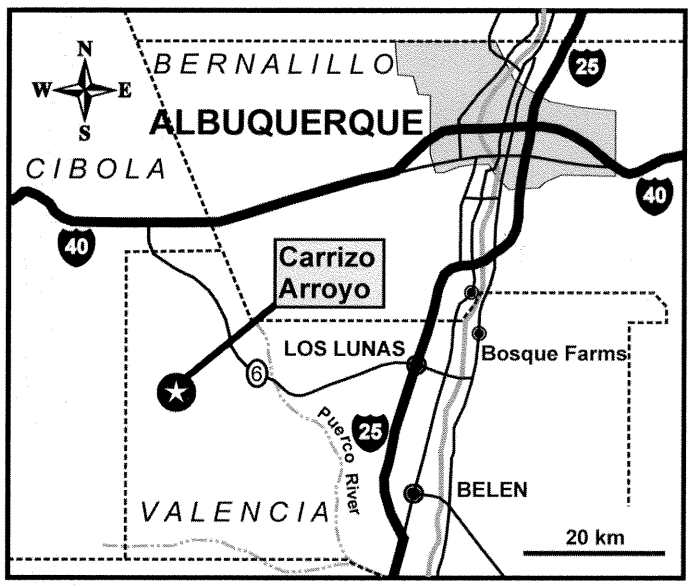


FIGURE 1. Location map of Carrizo Arroyo in central New Mexico.

## STRATIGRAPHY

We assign the Triassic section at Carrizo Arroyo to the Moenkopi Formation and Chinle Group (Figs. 2-3). Regionally, fossil evidence indicates that the Moenkopi Formation is of Middle Triassic age, whereas the lower Chinle Group is of Late Triassic age (Lucas, 1993; Lucas and Schoch, 2002).

### Moenkopi Formation

At Carrizo Arroyo, siliciclastic red beds of the Moenkopi Formation rest disconformably on Lower Permian (Leonardian) limestone of the San Andres Formation (Fig. 3A). Interbedded grayish red, trough-crossbedded or ripple-laminated, micaceous litharenite sandstone and pale reddish brown mudstone/siltstone are the dominant lithotypes (Figs. 3A, C). Thickness of the Moenkopi Formation at Carrizo Arroyo ranges from 17 to to 28 m (Fig. 2). The lithotypes and stratigraphic position of these strata support their assignment to the Anton Chico Member of the Moenkopi Formation, which regionally is present between the San Andres/Glorieta formations (Permian) and the base of the Chinle Group (Lucas and Hayden, 1989; Lucas and Heckert, 1994; Lucas et al., 1999).

### Chinle Group

Only the lowermost Chinle Group is preserved at Carrizo Arroyo. We assign these strata, about 30 m thick, to the Zuni Mountains and San Pedro Arroyo formations.

### Zuni Mountains Formation

At Carrizo Spring, the base of the Chinle Group is marked by a 0.3-m-thick, siliceous conglomerate consisting mostly of reddish-orange and reddish-brown jasper pebbles (Fig. 3D). This is a characteristic lithotype of the Shinarump Formation regionally (e.g., Lucas and Hayden, 1989; Heckert, 1997; Lucas et al., 1999). However, this thin conglomerate is overlain by ~2 m of color mottled siltstone and sandstone, strata traditionally referred to the "mottled strata" at the Chinle base (Stewart et al., 1972; Lucas and Hayden, 1989). Heckert and Lucas (2003) recently named the "mottled strata" in west-central New Mexico the Zuni Mountains Formation, and included thin, siliceous conglomerates in that unit. Therefore, we refer the lower ~2 m of the Chinle Group at Carrizo Arroyo to the Zuni Mountains Formation.

### San Pedro Arroyo Formation

Above the Zuni Mountains Formation at Carrizo Arroyo is a prominent, cuesta-forming limestone bed as much as 4 m thick (Figs. 2, 3A, E). This bed is generally a medium gray lime mudstone, with color mottles of grayish orange, pale reddish brown and dusky purple. Its base is locally silicified to chert, and its top includes large, orange masses of chert (Fig. 3F). Stratigraphic position and lithotype support assignment of this limestone to the Ojo Huelos Member of the San Pedro Arroyo Formation of Lucas (1991). The remaining Chinle Group section above the limestone is as much as 20 m of grayish red and pale olive bentonitic

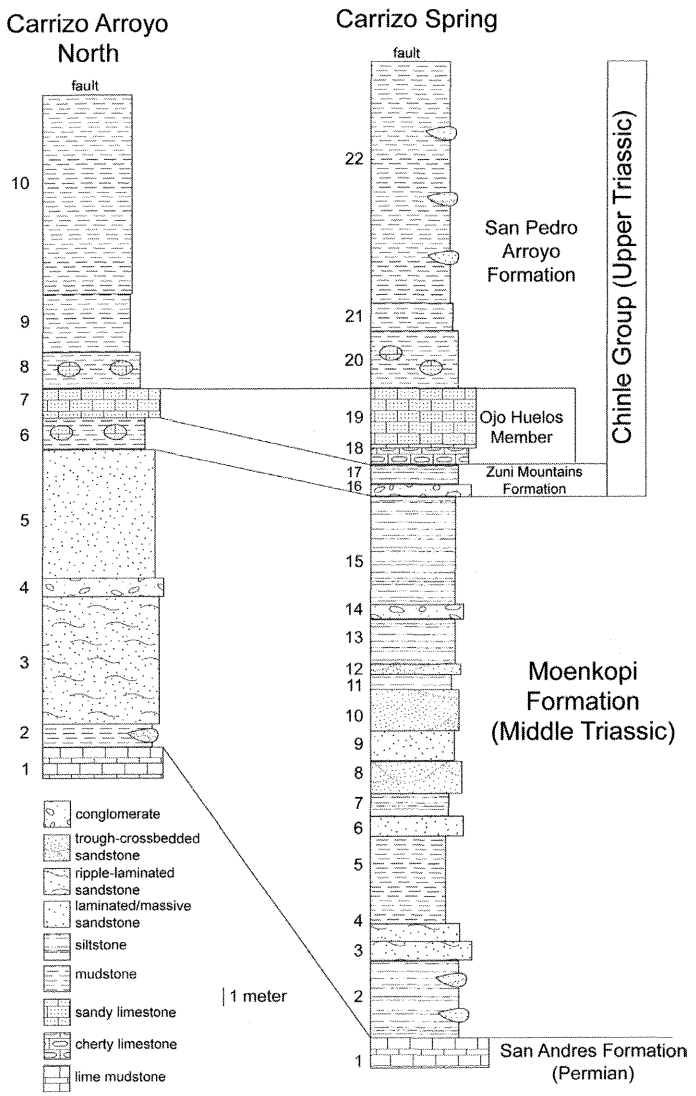


FIGURE 2. Measured stratigraphic sections of Triassic rocks at Carrizo Arroyo. See Appendix for description of numbered lithologic units.

mudstone with thin lenses of mostly greenish gray and grayish purple, very fine grained litharenite sandstone. These lithotypes are also characteristic of the lower part of the San Pedro Arroyo Formation (Lucas, 1991). A fault places Neogene strata of the Santa Fe Group on the incomplete Chinle Group section at Carrizo Arroyo (Callender and Zilinski, 1976).

Similar lower Chinle strata on the western side of the Lucero uplift are, nevertheless, assigned to the Bluewater Creek Formation of Lucas and Hayden (1989), and Heckert (1997) and Heckert and Lucas (1997) did assign most of the Chinle Group section at Carrizo Arroyo to the Bluewater Creek Formation. We view as somewhat arbitrary assignment of the post-Zuni Mountains Formation section of the Chinle at Carrizo Arroyo to the San Pedro Arroyo or Bluewater Creek formations, as Carrizo Arroyo is in the area where the two units laterally grade into one another. Given that the Ojo Huelos Member is present at Carrizo Arroyo, we prefer to refer the majority of the Chinle section to the San Pedro Arroyo Formation (Fig. 2).

### "Mancos Shale"

North of Carrizo Arroyo, Zilinski (1976, p. 19) assigned "a weathered fault slice 10 ft wide and 20 to 30 ft long" to the Mancos Shale, and Callender and Zilinski (1976) mapped a much larger outcrop as Cretaceous Mancos Shale between Chinle strata and Neogene Santa Fe Group. This outcrop of "Mancos" is part of our Carrizo Arroyo North section (Figs. 2, 3B) and is located in the NE1/4 NE1/4 NE1/4, sec. 6, T6N, R2W (at UTM 13, 309394E, 3850528N, NAD 27). We have closely studied the "Mancos" outcrop, and conclude that these strata are bentonitic mudstones and carbonaceous shales of the San Pedro Arroyo Formation that are as much as 14 m thick.

They do superficially resemble the Mancos Shale in lithology and outcrop pattern, but the following observations indicate that they instead pertain to the Chinle Group: (1) the Dakota Sandstone, which should be present between the Chinle and the Mancos Shale, is absent from this section, yet is present in significant (>10 m) thicknesses above Triassic strata elsewhere in the Lucero uplift (Lucas and Heckert, 1994); (2) the "shale" mapped by Callender and Zilinski consists of some dark, carbonaceous and bentonitic shales, but also includes local beds of diagenetic gypsum and poorly sorted sandstones—these are more commonly associated with the Chinle Group, especially deposits of the third lithofacies of the Bluewater Creek Formation (Heckert and Lucas, 2002a) than the more uniformly gray, bentonitic and calcareous shale characteristic of the Mancos Shale; (3) the strata in question rest directly on the Ojo Huelos limestone bed and include bluish-gray bentonitic mudstones and siltstones, strata that are typical of the lower Chinle Group throughout the Colorado Plateau (Stewart et al., 1972; Lucas, 1993); (4) there is no indication of Cretaceous marine fossils, either *in situ* or as float, in the area.

## SIGNIFICANCE OF THE OJO HUELOS MEMBER

Lucas (1991) named the Ojo Huelos "Bed" for 7.4+ m of limestone with interbedded grayish sandy mudstone in the San Pedro Arroyo Formation, and recognized its Late Triassic age on the basis of fossils of the skull of a metoposaur and phytosaur teeth. The type section of this unit was measured at Ojo Huelos, just across the Rio Grande valley from Carrizo Arroyo (Lucas, 1991). With Lucas' (1993) elevation of the Chinle to group rank, the Ojo Huelos Bed became a member of the San Pedro Arroyo Formation. Heckert and Lucas (2002b) documented microfossils from the Ojo Huelos Member at its type section; the assemblage is dominated by fish teeth and scales, especially of the chondrichthyan *Lissodus* and of actinopterygians.

Lucas (1991) recognized strata published by Lucas and Hayden (1989) in Carrizo Arroyo as the westernmost expression of the Ojo Huelos Member. Other than the Ojo Huelos Member strata, the Chinle sediments exposed at Carrizo Arroyo closely resemble the third lithofacies of the Bluewater Creek Formation (Heckert and Lucas, 2002a), as they consist primarily of dark bentonitic mudstones and carbonaceous shales with locally abundant, diagenetic gypsum. This is why Heckert and Lucas (1997) considered the "Ojo Huelos Member" in Carrizo Arroyo as an isolated occurrence of lacustrine limestone in the Bluewater Creek Formation.

Regardless of the stratigraphic nomenclature, the Ojo Huelos Member in south-central New Mexico and the lowermost Bluewater Creek Formation in west-central New Mexico consist of lacustrine limestones, some pedogenically overprinted, dark-colored, locally carbonaceous shales and other lithotypes indicative of shallow ponds and lakes in a mosaic of floodplain deposits and stable interfluves. The depositional environment was thus a vast lacustrine-palustrine system, similar to, but wetter than that posited for the Owl Rock Formation of the Chinle Group by Tanner (2000).

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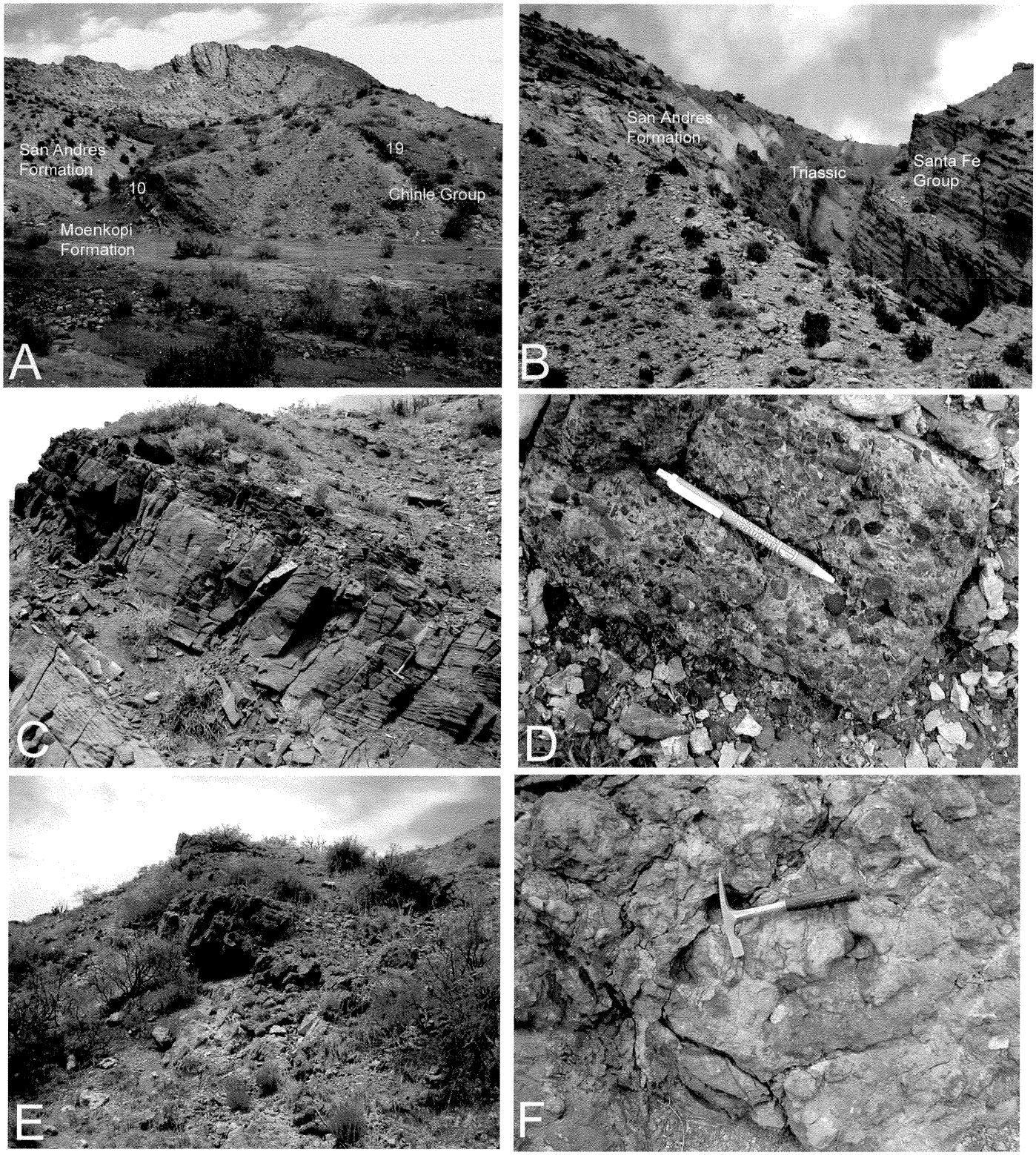


FIGURE 3. Selected photographs of Triassic strata at Carrizo Arroyo. **A,** Overview of section immediately north of Carrizo Spring. Some numbered units in measured section (Appendix) indicated. **B,** Overview of section at northern end of Triassic outcrop belt. **C,** Characteristic crossbedded sandstone of Moenkopi Formation (unit 8 of measured section at Carrizo Spring). **D,** Extrabasinal, chert-pebble conglomerate at base of Chinle Group (unit 16 of measured section at Carrizo Spring). **E,** Ojo Huelos Member (unit 19 of measured section at Carrizo Spring). **F,** Chert replacement of limestone at top of Ojo Huelos Member (top of unit 19 of measured section at Carrizo Spring).

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## APPENDIX-MEASURED SECTIONS

### Carrizo Arroyo North

Section measured in the NE1/4 NE1/4 NE1/4 sec. 6, T6N R2W, in a saddle between a San Andres surface (west) and a Santa Fe Group hogback (east). Strata strike N5°E and dip 59°E. Section measured 14 October, 1996, by A.B. Heckert.

**unit lithology** — **thickness (m)**

**Santa Fe Group:**

11 Sandstone and conglomerate; moderate orange pink (10R7/4); fine-grained to pebble conglomerate; lithic-rich, including rip-ups of all underlying units; very calcareous. — not measured

**fault**

**Chinle Group:**

**San Pedro Arroyo Formation:**

10 Heterolithic mudstones and shaly, dark-greenish gray (5G4/1) bentonitic slickensided shale; yellowish gray (5Y8/1) sublitharenites with diagenetic gypsum veins; rare lenses of moderate orange pink (10R7/4) to moderate reddish orange (10R6/6) lithic sandstone-poorly sorted; unit crops out as a yellowish-green slope in the saddle with much popcorn weathering and diagenetic selenite; calcareous. — 11.0

9 Mudstone; grayish purple (5P4/2) to grayish red purple (5RP4/2) with light olive gray (5Y6/1) mottling; bentonitic; not calcareous. — 3.3

8 Mudstone; pale red purple (5RP6/2) to grayish red purple (5RP4/2); much pedoturbation with light gray (N7) and light greenish gray (5GY8/1) nodules, some with moderate red (5R4/6) veins; very calcareous; porcellanites in places; bioturbation most prevalent in lower half of unit. — 1.8

**Ojo Huelos Member:**

7 Pedogenic limestone; greenish gray (5GY6/1) weathered light greenish gray (5GY8/1) to light gray (N7) fresh, highly calcareous; very nodular. — 1.0

**Zuni Mountains Formation:**

6 Mudstone and nodules of pedogenic limestone; greenish gray (5GY6/1) weathered, medium light gray (N6) fresh with dark gray (N3) to dark greenish gray (5GY4/1) silica growths and replacements; highly calcareous. — 1.8

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

**Moenkopi Formation:**

**Anton Chico Member:**

5 Sandstone; pale red (10R6/2) to grayish red (10R4/2); fine-grained, quartz and lithic rich; well-sorted subangular sublitharenite; calcareous; top is flaggy mud-pellet conglomerate of same colors with clasts 2-8 mm in diameter; unit forms a ribbed slope. — 7.4

4 Sandstone; weathers grayish red (10R4/2) to pale reddish brown (10R5/4) as light as light gray (N7) to light olive gray (5Y6/1) fresh; quartz-rich moderately sorted sub-litharenite; massive; ledge-forming; mud-pellet conglomerate at base; calcareous; forms a north-south-trending knife ridge. — 0.7-1.2

3 Sandstone; light olive gray (5Y6/1) and darker; fine-grained, well-sorted subangular sublitharenite; very slightly micaceous; much covered by debris from slope; flaggy; laminar to ripple laminar; calcareous. — 7.4

2 Mudstone and sandstone; yellowish gray (5Y7/2) to grayish yellow green (5GY7/2); poorly sorted lithic wacke; occasional mudstone pellets; mostly very fine- to medium-grained; not calcareous; much more flaggy than 1; forms a a gray-green band below 3. — 1.4

**disconformity: (Tr-0-2 unconformities of Pipiringos and O'Sullivan, 1978)**

**San Andres Formation:**

1 Limestone; medium light gray (N6) to light brownish gray (5YR6/1); highly calcareous; last thick slab on a stepped limestone dipslope. — not measured

## Carrizo Spring

Section measured in the SW1/4 SE1/4 SE 1/4 sec. 6 T6N R2W on north side of wash. Strata dip 31° to N83°E. Section originally measured by S. G. Lucas and S. N. Hayden and published by Lucas and Hayden (1989); remeasured by Lucas and A. P. Hunt.

| unit | lithology | thickness (m) |
|---|---|---|
| **Santa Fe Group** | | |
| **fault** | | |
| **Chinle Group:** | | |
| **San Pedro Arroyo Formation:** | | |
| 22 | Mudstone; grayish red (10R4/2); much covered; with thin lenses of very fine grained, litharenite sandstone that is light greenish gray (5GY8/1) and ripple laminated. | 15.0 |
| 21 | Mudstone; pale olive (10Y6/2). | 1.5 |
| 20 | Mudstone; very dusky purple (5P2/2); with nodules of pale yellowish brown (10YR6/2) sandy limestone (calcrete). | 3.0 |
| **Ojo Huelos Member:** | | |
| 19 | Limestone; medium gray (N5) with mottles of pale reddish brown (10R5/4) and grayish orange (10YR7/4); top nodular and locally cherty. | 3.4 |
| 18 | Cherty limestone; very pale orange (10YR8/2) and grayish orange (10YR7/4); vuggy. | 0.6 |
| **Zuni Mountains Formation:** | | |
| 17 | Siltstone and very fine grained sandstone; grayish purple (5P4/2); some orange, yellow and gray color mottles. | 1.5 |
| 16. | Conglomerate; grayish red (10R4/2) and pale greenish yellow (10Y8/2) matrix, clasts are moderate reddish orange (10R6/6) and moderate reddish brown (10R6/6); clasts are almost exclusively jasper pebbles; clast-supported. | 0.3 |
| **unconformity (Tr-3 unconformity of Pipiringos and O'Sullivan, 1978)** | | |
| **Moenkopi Formation:** | | |
| **Anton Chico Member:** | | |
| 15 | Siltstone; grayish red (10R4/2). | 6.5 |
| 14 | Conglomerate; matrix is pale reddish brown (10R5/4) very fine grained sandstone; clasts are very light gray (N8) calcrete pellets. | 0.6 |
| 13 | Siltstone; pale reddish brown (10R5/4); with calcrete nodules. | 2.4 |
| 12 | Sandstone; same colors and lithology as unit 10. | 0.3 |
| 11 | Siltstone; pale reddish brown (10R5/4); with calcrete nodules. | 0.8 |
| 10 | Sandstone; grayish red (10R4/2); micaceous litharenite; medium grained; trough crossbedded. | 2.3 |
| 9 | Sandstone; pale reddish brown (10R5/4); micaceous litharenite; fine grained; laminar; forms a notch. | 1.3 |
| 8 | Sandstone; grayish red (10R4/2); micaceous litharenite; medium grained; trough crossbedded; climbing ripples; scour base. | 1.7 |
| 7 | Siltstone; pale reddish brown (10R5/4). | 1.4 |
| 6 | Sandstone; pale red (10R6/2) and light greenish gray (5GY8/1); micaceous litharenite; medium grained; ledgy and nodular. | 0.7 |
| 5 | Mudstone; pale reddish brown (10R5/4). | 4.6 |
| 4 | Sandstone; same colors and lithology as unit 2. | 0.7 |
| 3 | Sandstone; same colors and lithology as unit 2; forms a prominent ripple-laminated ledge. | 0.8 |
| 2 | Siltstone slope with sandstone ledges; sandstone is pale yellowish brown (10YR6/2), fine-grained, micaceous litharenite that is ripple laminated. | 4.6 |
| **unconformity (Tr-0-2 unconformities of Pipiringos and O'Sullivan, 1978)** | | |
| **San Andres Formation:** | | |
| 1 | Limestone; light olive gray (5Y6/1) to light brownish gray (5YR6/1); lime mudstone. | not measured |

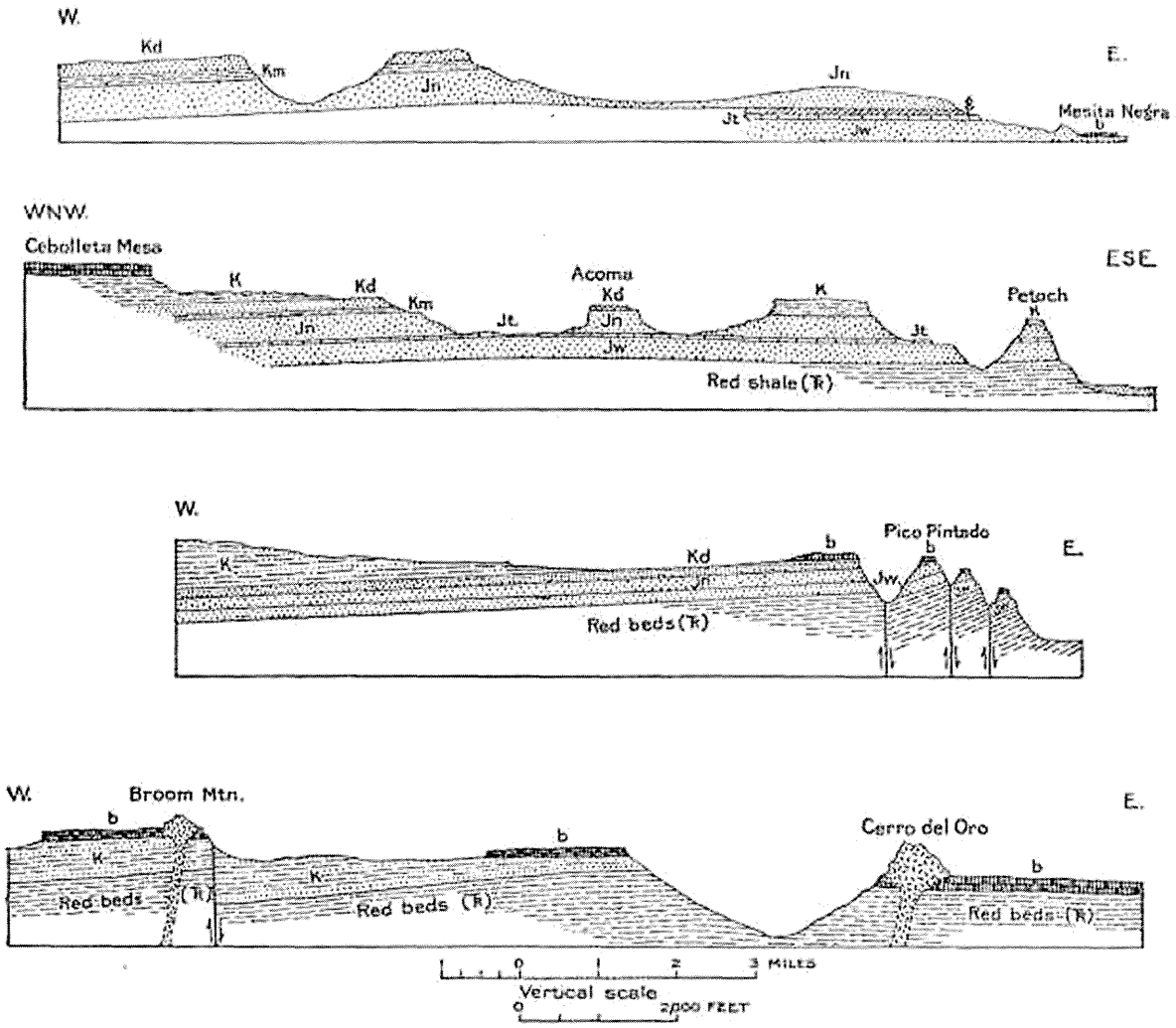


FIGURE 39.—Sections of escarpments from Mesa Gigante to beyond Acoma, central Valencia County. K, Cretaceous undifferentiated; Kd, Dakota sandstone; Km, Morrison formation; Jn, Navajo sandstone; Jt, Todilto formation (g, gypsum member); Jw, Wingate sandstone; Tr, Triassic; b, basalt.

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