Triassic stratigraphy of west-central New Mexico

Spencer G. Lucas and Steven N. Hayden

1989, pp. 191-211. https://doi.org/10.56577/FFC-40.191

in:

Southeastern Colorado Plateau, Anderson, O. J.; Lucas, S. G.; Love, D. W.; Cather, S. M.; [eds.], New Mexico Geological Society 40th Annual Fall Field Conference Guidebook, 345 p. https://doi.org/10.56577/FFC-40

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

TRIASSIC STRATIGRAPHY OF WEST-CENTRAL NEW MEXICO

SPENCER G. LUCAS[1] and STEVEN N. HAYDEN[2]
[1]New Mexico Museum of Natural History, P.O. Box 7010, Albuquerque, New Mexico 87194; [2]Department of Geology, University of New Mexico, Albuquerque, New Mexico 87131

Abstract—Triassic strata in west-central New Mexico are exposed over four, disjunct terranes: Largo Creek (western Catron County), Zuni Pueblo (western Cibola and southwestern McKinley counties), Bluewater (McKinley-Cibola counties) and Mesa Lucero (eastern Cibola–northern Socorro counties). The oldest Triassic strata in these terranes pertain to the Moenkopi Formation, which disconformably overlies the Permian San Andres Formation and is disconformably overlain by the Chinle Formation. The Moenkopi Formation in west-central New Mexico is as much as 68 m dominated by grayish-red and reddish-brown, lithic wackestones, mudstones and siltstones that yield charophytes, ostracodes, bones of capitosauroid amphibians and large footprints of *Chirotherium* reptiles indicative of an Early or Middle Triassic age.

Remaining Triassic strata in west-central New Mexico are assigned to five members of the Chinle Formation (in ascending order): Shinarump Member/mottled strata, Bluewater Creek Member, Petrified Forest Member (including lower and upper parts plus the Sonsela and Correo Sandstone beds), Owl Rock Member and Rock Point Member. As much as 24 m of silica-pebble conglomerate/sandstone and pedogenically modified and mottled siltstone, mudstone and sandstone pertain to the Shinarump Member and mottled strata. Root casts, previously identified as lungfish burrows, abound in the mottled strata near Fort Wingate.

The new term Bluewater Creek Member of the Chinle Formation is introduced here for strata in west-central New Mexico formerly termed Division D, lower red member or Monitor Butte Member of the Chinle Formation. The 100 m or more of Bluewater Creek Member are dominated by red sandstones and mudstones that contain an extensive fossil flora and some fossil vertebrates of Carnian age. In west-central New Mexico, the overlying Petrified Forest Member is more than 1000 m divided into lower and upper, mudrock-dominated portions by the Sonsela Sandstone Bed, and contains the Correo Sandstone Bed near its top.

The youngest Triassic strata in west-central New Mexico pertain to the Owl Rock Member (as much as 24 m, exposed as far east as Thoreau) and Rock Point Member (50+ m) of the Chinle Formation. Putative Triassic strata near Horse Mountain, Catron County are Permian, and a supposed karst filling ("cave") in the San Andres Formation at Cottonwood Creek, McKinley County is a delta-plain facies of the Permian San Andres Formation.

INTRODUCTION

Triassic strata in west-central New Mexico (Fig. 1) pertain to the Moenkopi and Chinle formations. Since Marcou (1856, 1858) first identified Triassic rocks in this part of the state, a variety of stratigraphic relationships and nomenclatures have been proposed. Much of this variety stems from the fact that Triassic strata in west-central New Mexico are exposed over four, disjunct terranes, and few workers have attempted to study Triassic stratigraphy in more than two of these terranes. These terranes (Fig. 1) are: (1) Bluewater terrane, the Triassic outcrop belt along the northern and western flanks of the Zuni Mountains, mostly between Gallup and Grants; (2) Zuni Pueblo terrane, the Triassic outcrops located primarily on the Zuni Indian Reservation in western Cibola County and southwestern McKinley County; (3) Largo Creek terrane, Triassic outcrops in the upper drainage of Largo Creek and its tributaries, far western Catron County; and (4) Mesa Lucero terrane, Triassic strata that crop out in and around the Lucero uplift of eastern Cibola and northern Socorro counties. Here, we clarify Triassic stratigraphic relationships and nomenclature in these four terranes, with particular emphasis on the Moenkopi Formation and lower part of the Chinle Formation. In this article, NMMNH refers to the New Mexico Museum of Natural History, Albuquerque. All fossil localities discussed in this paper are listed in Appendix 2. Rock colors follow Goddard et al. (1984).

PREVIOUS STUDIES

Many geologists have examined and commented on Triassic strata in west-central New Mexico since Marcou first recognized the Triassic in this area. Rather than exhaustively review the welter of literature that exists, we identify ten significant works that represent turning points or syntheses of our understanding of Triassic stratigraphy in west-central New Mexico (Fig. 2). For a more extensive review see Stewart et al. (1972a).

As a member of the 1853 Whipple Expedition, Jules Marcou identified Triassic strata in west-central New Mexico as "Trias" or "New Red Sandstone" (Marcou, 1856, 1858). John S. Newberry traversed portions of west-central New Mexico with the Ives and Macomb expeditions. He (Newberry, 1861, 1876) applied the informal term "salt group" to Permian and Triassic strata up to and including what is now termed the Sonsela Sandstone Bed, and he referred overlying Triassic and Jurassic strata to his "marl series."

Working in the Zuni Mountains–Mount Taylor area, Dutton (1885) first applied formal stratigraphic names to Triassic strata in west-central New Mexico. He coined the name Wingate Sandstone for strata now assigned to the Jurassic Entrada Sandstone. Dutton also used G. K. Gilbert's (1875) term Shinarump Conglomerate for strata now termed Sonsela.

Twenty-five years later, Darton (1910, p. 44–53) reviewed in detail the Triassic strata exposed throughout west-central New Mexico and concluded that "the classification of the Triassic rocks in Arizona and New Mexico is still in rather an unsatisfactory condition, especially as to correlation with formations in other regions." Below Dutton's (1885) Wingate, Darton assigned all the Triassic strata to the "Shinarump group." Darton equated Dutton's "Lower Trias" with Ward's (1901) "Leroux formation," at the base of which he identified the "Shinarump conglomerate." Below his "Shinarump," Darton termed the Triassic strata "Moencopie(?) formation" (= "Moencopie beds" of Ward [1901]; = Moenkopi Formation of later workers) above "Pennsylvanian" strata equivalent to the Aubrey Group of northern Arizona.

Darton (1928) modified little his earlier conclusions. However, he did follow the practice of the U.S. Geological Survey in abandoning Ward's (1901) term Leroux in favor of Gregory's (1915) name Chinle. Clearly, in 1910 and in 1928, Darton erred in correlating what is now known to be the Sonsela Sandstone Bed in west-central New Mexico with the Shinarump Conglomerate in Arizona. Consequently, he assigned underlying Triassic strata to the Lower-Middle Triassic Moenkopi Formation. Apparently, Darton was unaware of the fossils reported by Mehl et al. (1916) from Darton's "Moenkopi" strata at Fort Wingate (Bluewater Creek Member of Chinle Formation of this paper). These Late Triassic reptiles provided paleontological evidence that Darton's (1910, 1928) use of Moenkopi in west-central New Mexico was inappropriate.

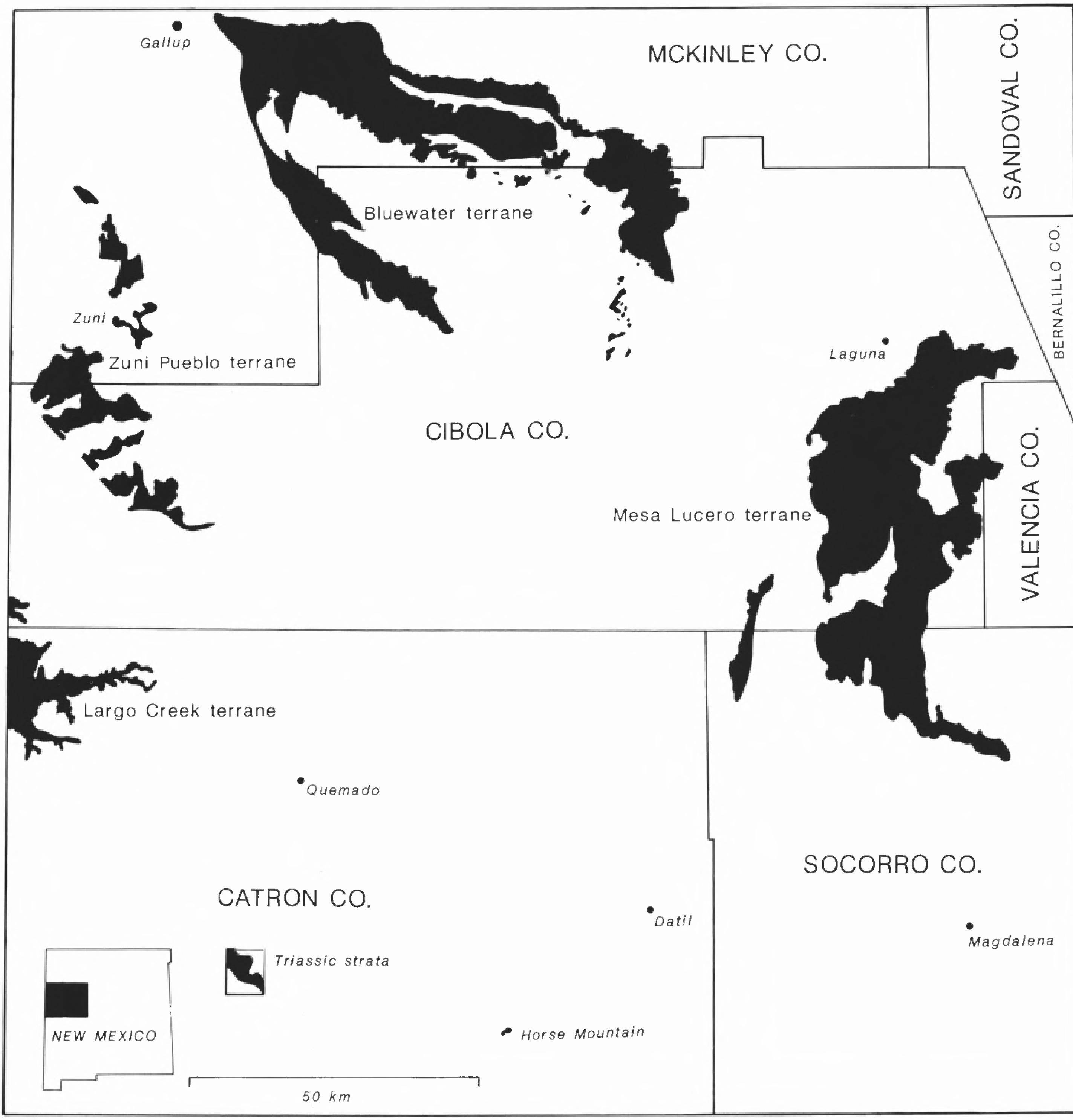

FIGURE 1. Distribution of Triassic strata in west-central New Mexico (after Dane and Bachman, 1965) and location of the four Triassic terranes (Largo Creek, Zuni Pueblo, Bluewater, Mesa Lucero) discussed in this paper.

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

Smith (1954, 1957), working to the west in the Bluewater terrane, followed McKee (1951, 1954), who argued that both the Moenkopi and the Shinarump are not present in the west-central New Mexico. Smith thus opted for an informal subdivision of the Triassic strata in this area, all of which he assigned to the Chinle Formation. Smith's lower and upper members were mudrock-dominated and split by the sandstone-dominated middle member. Smith also assigned to the Correo Sandstone Member upper Chinle sandstones west of Mesa Gigante that were well down in the Chinle-mudrock section.

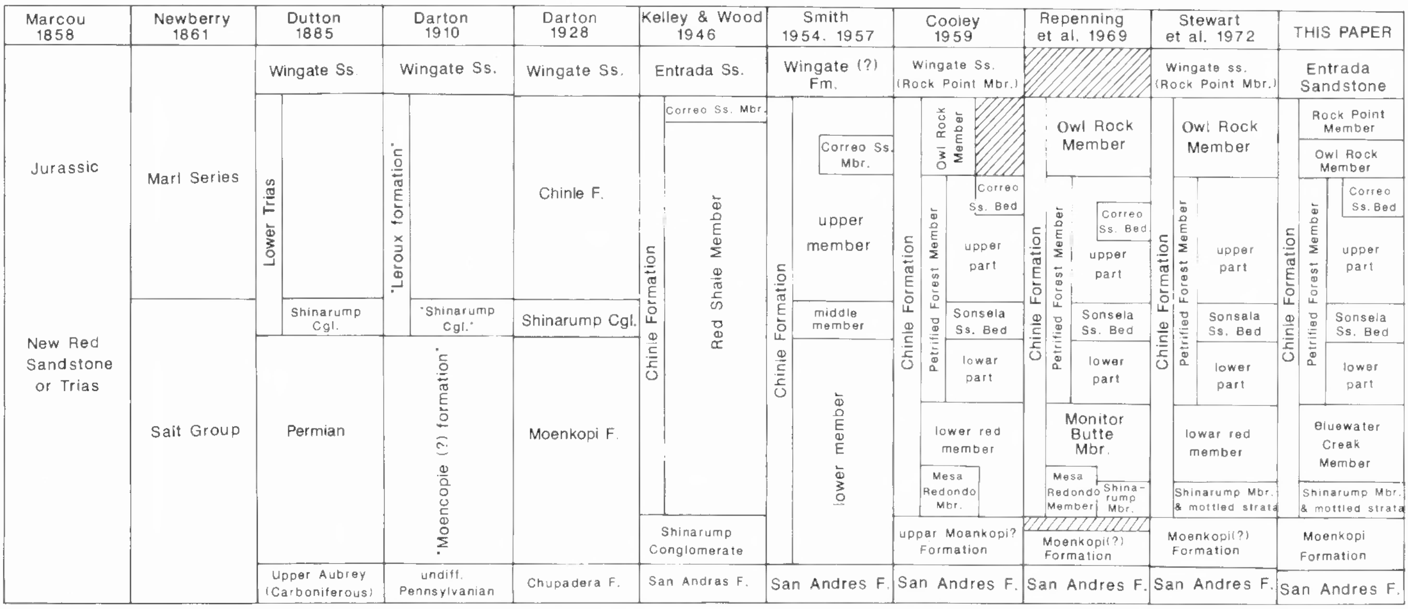

FIGURE 2. Stratigraphic nomenclature applied by some previous workers to Triassic strata in west-central New Mexico compared with the nomenclature advocated in this paper.

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

Repenning et al. (1969) presented only one significant change from the stratigraphy of Cooley. This was their use of Monitor Butte Member instead of lower red member in the Bluewater terrane. Furthermore, Repenning et al. (1969) also used the term Mesa Redondo Member for lower Chinle strata in the Zuni Pueblo terrane that interfinger with the base of their Monitor Butte Member in the subsurface.

Stewart et al. (1972b, c) followed the nomenclature of Cooley with few significant changes. The only addition was their recognition of the "mottled strata" at the base of the Chinle in west-central New Mexico. The stratigraphic nomenclature we advocate here (Fig. 2) is justified in what follows. It represents, in particular, our effort to clarify what we perceive as some confusion regarding the stratigraphy of Triassic strata below the Sonsela Sandstone Bed in west-central New Mexico.

MOENKOPI FORMATION

Middle Triassic strata are present between the Permian San Andres Formation and the Upper Triassic Chinle Formation in the Bluewater terrane and as erosional remnants on a surface of the San Andres Formation in the Mesa Lucero terrane. Well-preserved sections are found along the central part of the Lucero uplift on and between Mesa Gallina and Chicken Mountain. Extensive outcrops also are developed on the northern end of the Lucero uplift south of Correo and I-40 on the area covered by the White Ridge 7.5-minute quadrangle. Here, incomplete Moenkopi sections are capped by Quaternary travertine. In the Zuni Mountains, the Moenkopi is poorly exposed, being mostly covered by vegetation and colluvium. However, particularly clear sections can be observed at Upper Nutria, McGaffey–Fort Wingate and Bluewater (Fig. 3). The Moenkopi Formation is not exposed in the Largo Creek terrane and is only exposed in the Zuni Pueblo terrane as small fault blocks south of Ojo Caliente Reservoir in sec. 27, T8N, R20W (Kues and Lucas, 1989).

Contacts, lithology and facies

The Moenkopi Formation in west-central New Mexico consists of interbedded conglomerate and sandstone (20.6%), siltstone (49.6%) and mudstone (29.9%) bounded by profound erosional unconformities (Fig. 3). The surface of the underlying Permian San Andres Formation shows extreme weathering and the development of paleotopography on a leveled surface with abundant goethite pseudomorphs after pyrite making up a crust as much as 1.5 cm thick at Mesa Gallina. Nearby areas like Riley (Stewart et al., 1972c) and the northeastern flank of the Zuni Mountains (Cooley, 1959a) show a karst topography developed in the top of the San Andres Formation.

In the Lucero uplift, paleotopographic relief is indicated by the varying thickness of the basal, white-to-yellow mudstones and siltstones of the Moenkopi (Fig. 3). On Mesa Gallina, these basal Moenkopi sediments are as much as 9 m thick and contain microfossils that suggest they are of lacustrine origin (Kietzke, 1989b). However, in outcrops on the White Ridge quadrangle, these strata are 0.8 to 3.7 m thick. Based on sedimentary structures, such as lateral accretion sets, small-scale trough crossbedding and current ripples, we interpret these strata as the deposits of meandering fluvial systems (cf. Collinson and Thompson, 1982).

We measured stratigraphic sections of the Moenkopi Formation at Upper Nutria (Fig. 4A), Fort Wingate, Bluewater, San Rafael, Mesa Gallina and White Ridge (Fig. 3). Based on the sandstone-body geometry (Friend et al., 1979; Blakey and Gubitosa, 1984) in these sections, we recognize three phases of Moenkopi deposition in west-central New Mexico.

The first phase (Fig. 5A) begins with white, yellowish-gray to gray, light-pink, light-orange and greenish-yellow, massive to thinly laminated and ripple-laminar siltstones and silty mudstones interspersed with very fine- to fine-grained sandstones of the same colors (clastic rock classification follows Williams et al., 1982) which may have thin conglomeratic bases of limestone and intraformational siltstone rip-up clasts. The end of this phase (Figs. 3, 5A) consists mainly of reddish-brown, ripple-laminar siltstones and dusky-red, silty mudstones with light-greenish-gray to grayish-yellow mottling, intercalated with very fine- to fine-grained, reddish-brown to grayish-red, lenticular bodies of sandstone and sandy siltstone. The sandstones are lithic wackes that have

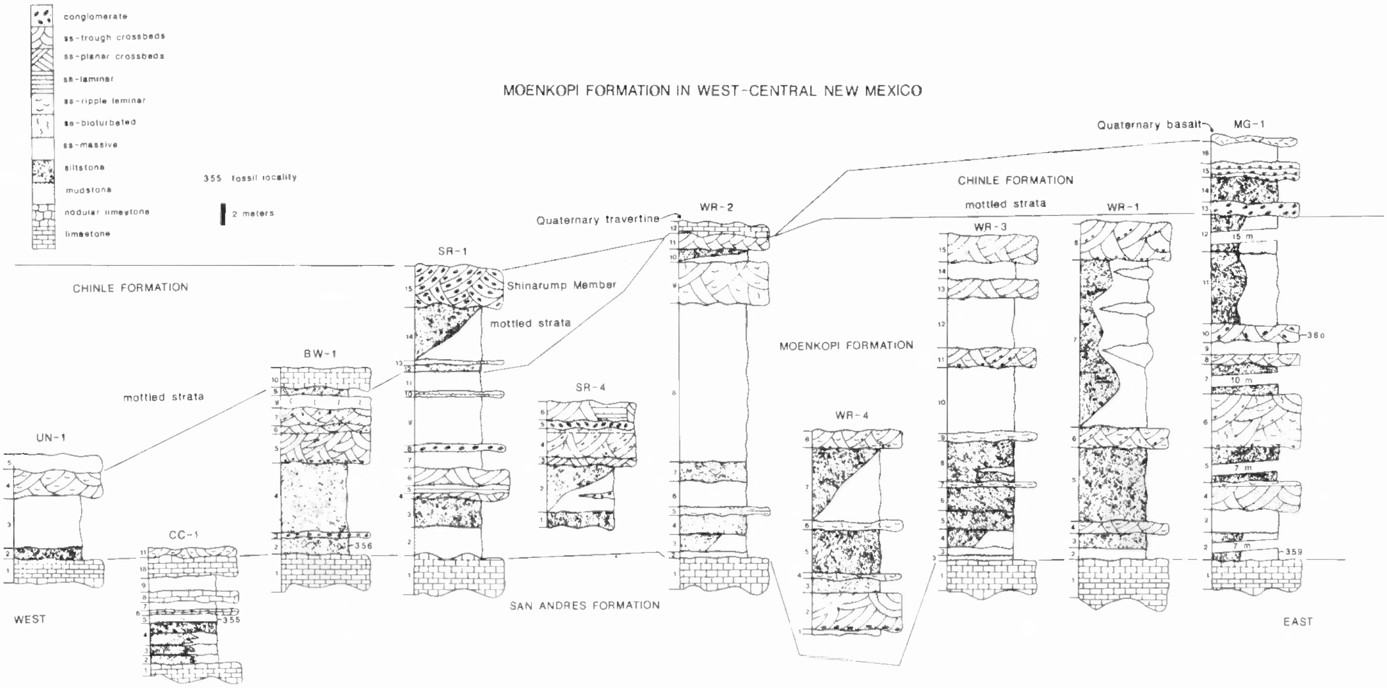

FIGURE 3. Measured stratigraphic sections of the Moenkopi Formation in west-central New Mexico. See Appendix 1 for descriptions of lithologic units.

varying amounts of fine-grained matrix up to the point where they grade into sandy siltstones.

The second phase of Moenkopi deposition is represented by the same types of siltstones and silty mudstones as the upper part of the first phase, except that the sandstones are dominantly pebbly, lithic-wacke-to pebbly, subarkosic, wacke-type sandstones (Figs. 3, 5B) that occur in wide, multistoried, sheet-sandstone complexes (nomenclature after Blakey and Gubitosa, 1984) with coarse intraformational conglomerates above scour bases. These conglomerates consist of limestone, chert and siltstone rip-up clasts as much as 5 cm in diameter and also contain extraformational pebbles of metaquartzite and other rock fragments as much as 3 cm in diameter. They range from clast- to matrix-supported and have a matrix of immature sand from 700 μm to fine silt and are yellowish brown, grayish pink and grayish red.

The sandstones are identical to the matrix in conglomerates and contain extraformational pebbles of metamorphic and sedimentary rock fragments up to 2.0 cm in diameter. They are cemented by intrasparite-calcite cement that probably recrystallized from detrital limestone clasts in the sand (cf. Williams et al., 1982). These sandstones generally occur above conglomeratic bases, have reactivation surfaces every 0.5 to 1.0 m and may be 5 m or more thick. They are brownish red to grayish red to dark gray. Lenticular ribbon-type and narrow-sheet sandstones (Blakey and Gubitosa, 1984) also occur in the ripple-laminar siltstones between the major sheet-sandstone complexes. Some finer-grained sand bodies are present in 5-to-10-cm-thick layers at the top of the sheet-sand bodies and may represent crevasse-splay-type-overbank deposits. These are overlain by ripple-laminar bioturbated siltstones which we interpret as finer-grained overbank deposits, which, in turn, are overlain by massive, dusky-red, silty mudstones with greenish-gray to grayish-yellow mottling which may represent swampy interfluvial areas or possibly paleosols. Some layers of calcrete and small vertical mottling may represent paleosols with root casts, but too few data have been collected to be certain of their origin.

The third and last phase of Moenkopi deposition (Figs. 3, 5C) consists of one 25-to-30-m-thick, fining-upward sequence. It differs from the second phase of deposition only in the nature of its basal conglomerate/sandstone complex. This is another wide sheet complex, but it has more and thicker conglomerates which show pebble imbrication, and the sands are thinner and tend to be planar-to-tabular crossbedded rather than trough crossbedded. The clast sizes are similar to those in the lower phase, but these conglomerates are dominated by limestone pebbles with a few siltstone clasts. We interpret this as deposition by a more braided-type-stream complex (Collinson and Thompson, 1982; Miall, 1984). The overlying siltstones and silty mudstones are identical to those below.

The Moenkopi Formation in west-central New Mexico is disconformably overlain by the Shinarump Member or "mottled strata" (Stewart et al., 1972b) of the Upper Triassic Chinle Formation. These strata consist of silica-pebble conglomerates, quartzose sandstones and siltstones/fine sandstones that are mottled white, yellow, orange and purple (Fig. 4C, E–F). They are very distinctive and easily distinguished from Moenkopi sediments. Other aspects of the lithology, thickness and distribution of the Moenkopi Formation in west-central New Mexico are discussed by Hayden and Lucas (1988a, b, 1989).

Paleontology

Fossils are not plentiful in the Moenkopi Formation in west-central New Mexico. On Mesa Gallina, the basal conglomerate of the third phase of deposition yielded three incomplete vertebrae of an unidentified archosaurian reptile and an interclavicle from a capitosauroid amphibian (Fig. 8B–F) from NMMNH locality 360 (Appendix 2). These fossils indicate an Early or Middle Triassic age for Moenkopi strata in the Lucero uplift.

Kietzke (1988, 1989a, b) identified microfossils (ostracodes and charophytes) from some of the fine-grained units in the Moenkopi section at Mesa Gallina. The ostracodes pertain to the genera *Darwinula*, *Darwinuloides* and, possibly, *Gerdalia*. The charophytes are two species of *Porochara* and, possibly, one species of *Altochara*. Spirorbid worms of a possible new taxon also are present. These fossils also indicate an Early or Middle Triassic age for the Moenkopi strata from which they were collected. Most of these microfossils came from the basal unit of the Moenkopi Formation on Mesa Gallina (NMMNH locality 359). This unit probably was deposited in a clear, but saline to mineralized, shallow lake (Kietzke, 1989b).

Near Bluewater Creek, we discovered a reptile-footprint fauna near the base of the Moenkopi Formation (Fig. 4D) at NMMNH locality 356. Besides a variety of swimming traces, this ichnofauna is dominated by footprints of a "large-manus *Chirotherium*" like those described from the Moenkopi Formation in Arizona by Peabody (1948).

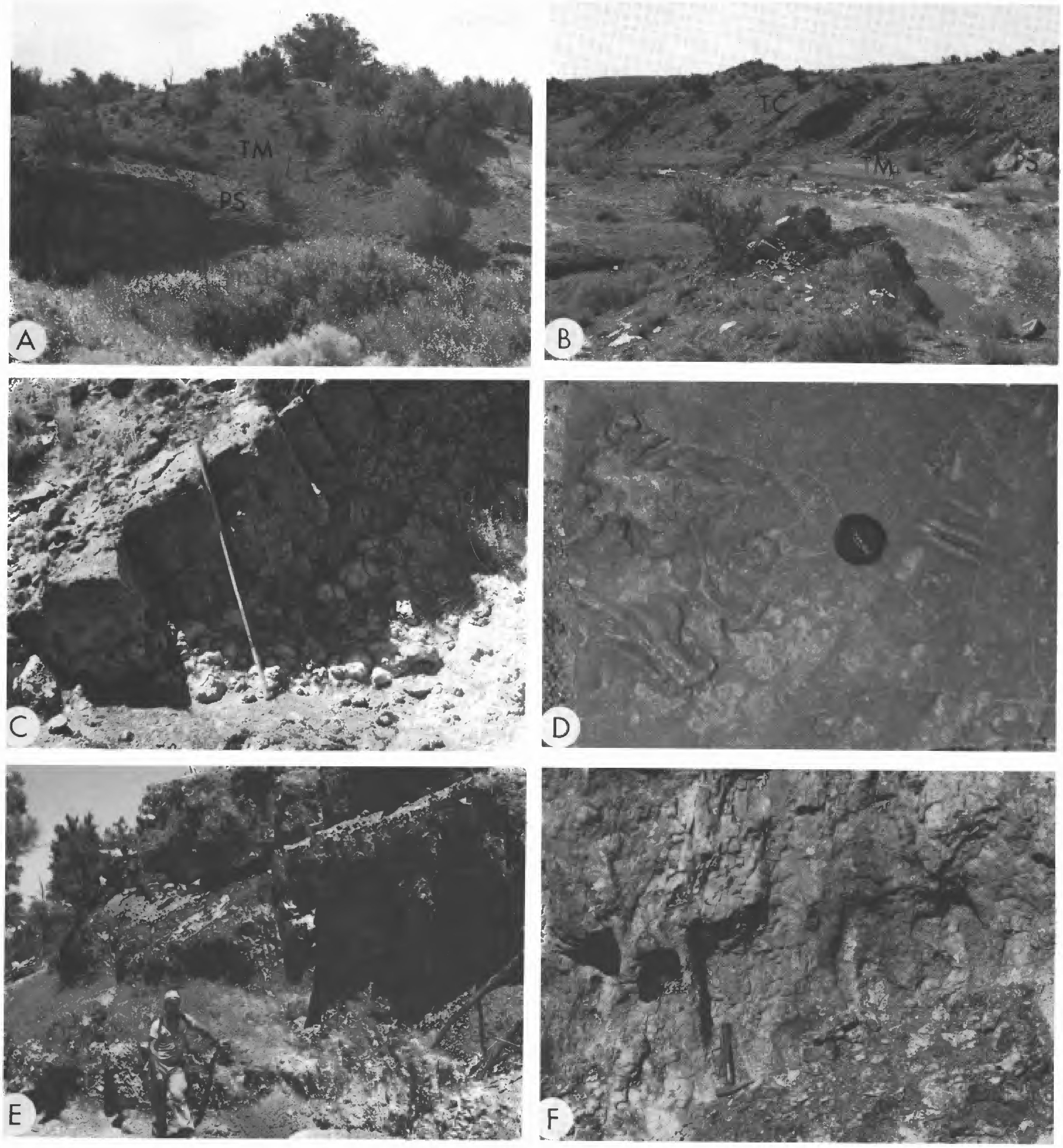

FIGURE 4. Photographs of strata of the Moenkopi Formation and mottled strata of the Chinle Formation in west-central New Mexico. A, Moenkopi strata (TM) above the San Andres Formation (PS) at Upper Nutria, NW¼ SW¼ sec. 8, T12N, R16W, McKinley County. B, San Andres (PS), Moenkopi (TM) and Chinle (TC) strata at Carrizo Spring on the eastern edge of the Lucero uplift, SE¼ SE¼ sec. 6, T6N, R2W, Valencia County. C, Detail of the mottled strata including a limestone bed at Carrizo Spring. D, Reptile-swimming traces in the lowermost Moenkopi Formation at NMMNH locality 356, Bluewater Creek area. E, Thick, pedogenically modified siltstones and sandstones of the mottled strata of the Chinle Formation at Fort Wingate, SE¼ NW¼ sec. 9 (unsurveyed), T14N, R16W, McKinley County. F, Putative lungfish burrows (actually root casts) in the mottled strata at Fort Wingate, NMMNH locality 358.

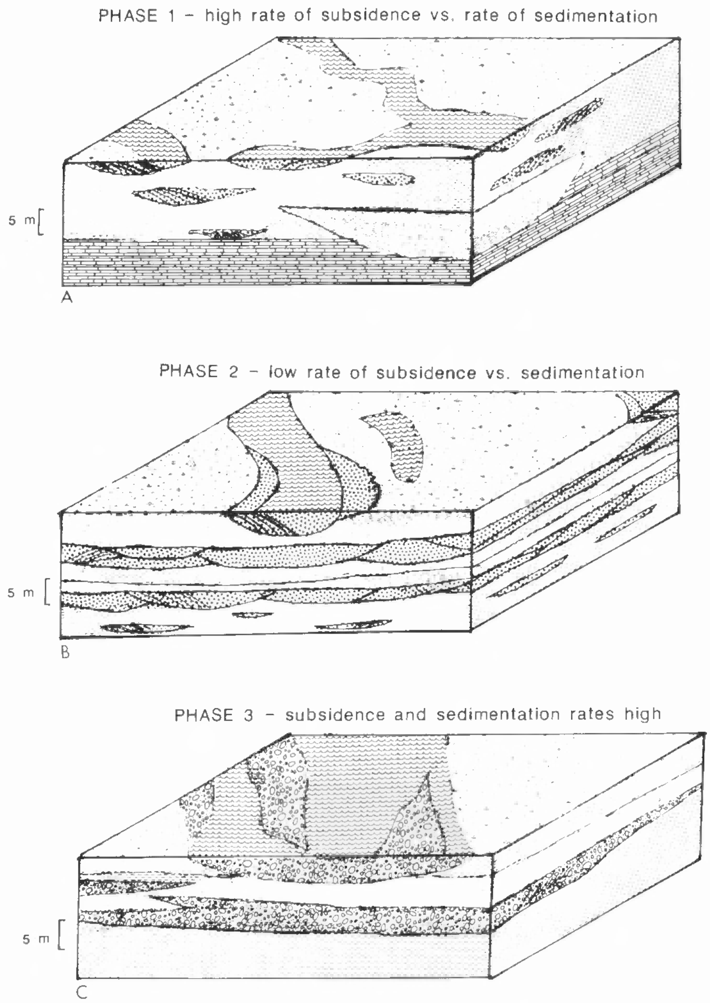

FIGURE 5. The three phases of Moenkopi deposition in the Lucero uplift of west-central New Mexico.

Deposition and paleogeography

The first phase of Moenkopi deposition is interpreted as the filling of topographic lows on an erosion surface with ponds or lakes developed in the lowest areas (Fig. 5A). As this topography filled and leveled, the dominant mode of sedimentation became small meandering streams, as indicated by abundant, small multistoried or complex, ribbon-type sandstone bodies (cf. Friend et al., 1979). The large amount of silt and mud, and the small and isolated nature of the sand bodies, indicate that the rate of subsidence may have been high with respect to the rate of sedimentation (Blakey and Gubitosa, 1984).

Overlying this sequence, the second phase of Moenkopi deposition consists of interbedded mudstones, siltstones and wide sheet-sandstone bodies with coarser basal conglomerates. There are abundant pebbles in the sands, and the lesser number of lateral accretion type deposits and abundant trough and planar crossbeds suggest less meandering of the streams. This sedimentary regime is indicative of a lower rate of subsidence in relation to sediment supply (Friend et al., 1979). Channels had time to fill with sediment and were forced to avulse laterally rather than being buried swiftly. This winnowed out the fine-grained overbank deposits, leaving sand instead. These sandstone bodies have a high width-to-height ratio (>100) which meets the criterion for wide-sheet sandstones (Blakey and Gubitosa, 1984).

The third phase of Moenkopi deposition consists of one sequence 25–30 m thick. This has a scoured base filled by a wide, sheet-sandstone/conglomerate complex that is as much as 5 m thick, overlain by 6–8 m of ripple-laminar siltstone overlain, in turn, by as much as 20 m of red mudstone with greenish gray to grayish yellow mottling and a nodular calcrete layer 1.3 m thick located 13 m above the base. High subsidence and high sediment supply produced this sequence.

Paleocurrent azimuths we recorded in west-central New Mexico indicate northerly flowing streams during the first two phases of Moenkopi deposition followed by a shift to southerly paleoflow in the third phase. Vector means for the three phases of Moenkopi deposition were calculated from E-W and N-S components (Tucker, 1982). They are 331° for phase 1, 28° for phase 2 and 161° during phase 3.

A relatively proximal source area to the south is suggested by the generally northerly paleoflow and by the lack of textural and mineralogical maturity of Moenkopi sandstones. This is in accord with Stewart et al. (1972c), who postulated a source area for Moenkopi sediments located in southeastern Arizona and southwestern New Mexico (Mogollon highland). Bilodeau (1986) posited the closest source area for Middle Triassic strata as an island-arc system in northwestern Mexico or southeastern California. This does not agree with our data.

CHINLE FORMATION

We recognize five members of the Chinle Formation in west-central New Mexico (in ascending order): Shinarump Member/mottled strata, Bluewater Creek Member, Petrified Forest Member, Owl Rock Member and Rock Point Member.

Shinarump Member/mottled strata

The Chinle Formation rests with profound disconformity on the Moenkopi Formation across west-central New Mexico. This disconformity is marked by silica-pebble conglomerate and quartzose sandstone that represents the easternmost outcrops of the Shinarump Member, and by pedogenically modified siltstones, mudstones and sandstones that Stewart et al. (1972b) termed the "mottled strata." Sandstones we identify as Shinarump in west-central New Mexico are not mappable at a scale of 1:24,000 nor can they be traced over long distances. They are yellowish gray to light brown, trough-crossbedded, quartzarenites with silica- (usually chert) pebble conglomerates above Moenkopi strata or on (or within) mottled strata that overlie the Moenkopi.

The lower Chinle is not exposed in the Largo Creek terrane and is very poorly exposed in the Zuni Pueblo terrane. However, along the northeastern flank of the Atarque monocline south of Ojo Caliente Reservoir, strata we identify as Shinarump and mottled strata crop out (Kues and Lucas, 1989). In the S$^1/_2$ SW$^1/_4$ NW$^1/_4$ sec. 27, T8N, R20W and extending westward into sec. 28, the mottled strata consist of grayish-purple, very dusky-purple, pale reddish-brown and grayish-orange, sandy siltstone. Just to the east, in the SW$^1/_4$ SE$^1/_4$ SE$^1/_4$ NW$^1/_4$ sec. 27 are pale red and very pale orange quartzarenites with some chert-pebble conglomerate and silicified fossil wood that we identify as Shinarump. Because of faulting, we were unable to determine the thicknesses of these units.

The most extensive exposures of the mottled strata in west-central New Mexico are in the Bluewater terrane. South of Fort Wingate, 24+ m of mottled strata are exposed between the Moenkopi Formation and Bluewater Creek Member of the Chinle (Figs. 4E–F, 6). Here, the mottled strata are dominated by grayish-red-purple and grayish-purple siltstones and pale-pink to brownish-black mudstones. In contrast, near Bluewater Creek, the mottled strata are 7.6 m of olive-gray and brownish-gray, sandy limestone (Fig. 6).

At Fort Wingate, extensive vertical, tubular structures in the mottled strata (Figs. 4E–F, 9A–D) were identified as lungfish burrows by Dubiel et al. (1987). We, however, believe these trace fossils are rhizoliths, specifically root casts. McCallister (1988) well explained why these structures are not lungfish burrows, and Dubiel et al.'s (1988) response to his arguments does not refute his main points. In shape and texture, the trace fossils from Fort Wingate closely resemble root casts (Klappa, 1980). However, they do not branch, as Dubiel et al. (1987) noted. We posit that they represent casts of the nonbranching roots of a primitive tree-like plant, perhaps *Neocalamites* or a similar form (cf. Daugherty, 1941).

In the Mesa Lucero terrane, mottled strata rest directly on the Moen-

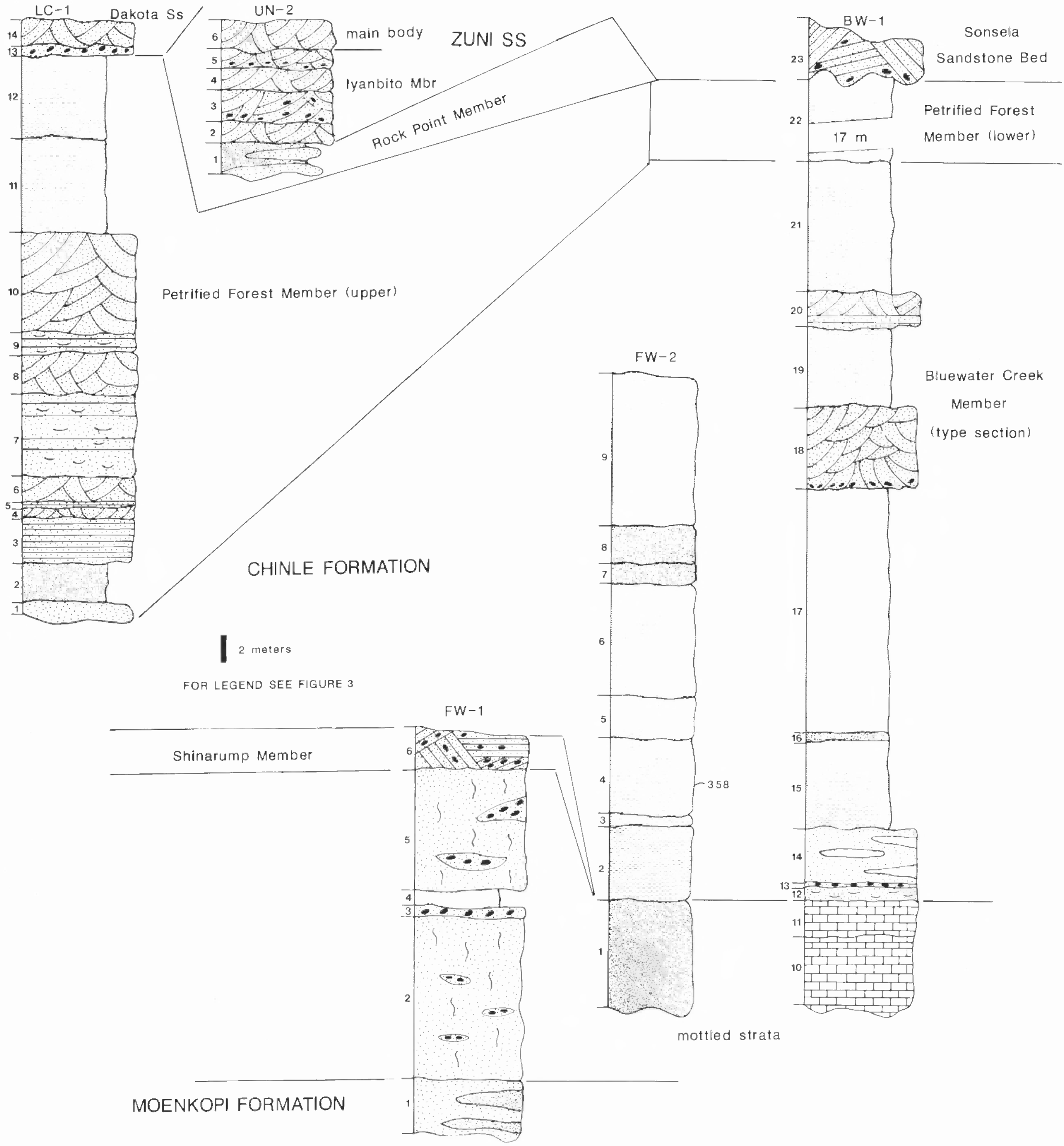

FIGURE 6. Measured stratigraphic sections of portions of the Chinle Formation in west-central New Mexico. See Appendix 1 for descriptions of lithologic units.

kopi (Figs. 3, 4B–C). We know of no evidence of the Shinarump Member in this terrane except for some lenses of silica-pebble conglomerate within the mottled strata.

Bluewater Creek Member

The stratigraphic unit previously referred to as "Division D" of the Chinle Formation (Gregory, 1917), "lower red member" of the Chinle Formation (Cooley, 1957, 1959a) or "Monitor Butte Member" of the Chinle Formation (Repenning et al., 1969; Ash, 1978) is named by us the Bluewater Creek Member of the Chinle Formation. Its type section is units 12 through 21 of our measured stratigraphic section BW-1 (Fig. 6; Appendix 1) measured in the W1/2 NE1/4 sec. 36, T13N, R12W, Cibola County. The name of this new member of the Chinle Formation is from Bluewater Creek, near the type section.

The Bluewater Creek Member rests with apparent conformity on the mottled strata of the Chinle Formation and is conformably overlain by the lower part of the Petrified Forest Member. At its type section (Fig. 7C), it is 52 m dominated by grayish-red and reddish-brown, sandstone, silty mudstone and sandy siltstone. The Bluewater Creek Member is present throughout the Bluewater terrane (e.g., Fig. 7a) and apparently present in the subsurface in the Zuni Pueblo terrane where it interfingers with Cooley's (1958) Mesa Redondo Member (Repenning et al., 1969). It may be absent in the Mesa Lucero terrane (Stewart et al., 1972b, pl. 4), but further study of the lower Chinle is needed here. Bluewater Creek Member should replace the term "lower red member" in the Defiance uplift of northeastern Arizona where it reaches thicknesses of 100 m or more (Stewart et al., 1972b).

The presence on the southeastern Colorado Plateau of a lower, red, sandy interval of the Chinle Formation between the Shinarump Member/mottled strata and the lower part of the Petrified Forest Member has been well documented (Cooley, 1957, 1959a; Repenning et al., 1969; Stewart et al., 1972b). In the vicinity of Cameron in northern Arizona, homotaxial strata are termed the "sandstone and mudstone member" (Stewart et al., 1972b) or "sandstone and siltstone member" (Repenning et al., 1969). In east-central Arizona, in the Holbrook–St. Johns area, homotaxial strata are the Mesa Redondo Member of the Chinle Formation (Cooley, 1958). And, in the area between the San Rafael Swell of east-central Utah and the Four Corners, the Monitor Butte Member represents the homotaxial portion of the Chinle Formation.

The "sandstone and mudstone member" of the Chinle Formation near Cameron is not physically continuous with similar strata to the south and east (Stewart et al., 1972b, pl. 4). The Mesa Redondo Member thins eastward to either pinch out or, as a thin tongue, interfingers with the Bluewater Creek Member in the subsurface at Zuni Pueblo (Repenning et al., 1969). The term Monitor Butte Member has been used in west-central New Mexico for strata we term Bluewater Creek Member (Repenning et al., 1969; Ash, 1969, 1978). However, we believe use of Monitor Butte Member here is inappropriate.

At its type section at Monitor Butte in San Juan County, southeastern Utah, the Monitor Butte Member is dominantly greenish-gray, bentonitic claystone and clayey, fine-grained sandstone (Stewart, 1957; Stewart et al., 1972b). These lithologies characterize the Monitor Butte Member throughout southeastern Utah (Stewart et al., 1972b). We believe the name Monitor Butte should be restricted to these lithologies. The sandier, red-bed facies to the south and southeast, homotaxial with the Monitor Butte Member, is what we term the Bluewater Creek Member.

The Bluewater Creek Member should not be confused with the "Bluewater Formation" of Talmadge and Wooton (1937), a unit that lacked a type section and was not used by subsequent workers. Talmadge and Wooton (1937, p. 30) proposed the "Bluewater Formation" to encompass the strata in west-central New Mexico that Darton (1910, 1928) termed Moenkopi (Fig. 2). It is equivalent to strata now termed Moenkopi and Chinle in this area.

The extensive fossil floras described from the Fort Wingate area by Ash (e.g., 1967, 1969, 1978, 1989) are from the upper and lower portions of the Bluewater Creek Member. This places the Bluewater Creek Member in the *Dinophyton* floral zone of Ash (1980).

Ash (1978) introduced the term "Ciniza Lake Beds" as a formal stratigraphic name to refer to 1.5 m of carbonaceous shale that crops out over an area 250 m by 550 m southeast of Fort Wingate (Fig. 7B). This lake deposit is within the Bluewater Creek Member, but is so thin and of such limited aerial extent that attaching a formal stratigraphic name to it strikes us as pointless. Therefore, we abandon the term Ciniza Lake Beds of Ash (1978).

Besides fossil plants, the lake beds southeast of Fort Wingate contain conchostracans (*Cyzicus* (*Lioestheria*) *wingatella*), scales of the coelacanth fish *Chinlea* and numerous coprolites (Ash, 1978). From strata of the Bluewater Creek Member near Fort Wingate, Mehl et al. (1916) described phytosaur postcrania (Fig. 8G–K) and teeth which they tentatively identified as *Palaeorhinus* and *Angistorhinus*. However, these specimens clearly are generically indeterminate (Ballew, 1989; Hunt and Lucas, 1989). Camp (1930) also reported indeterminate phytosaurs from the Bluewater Creek Member near Fort Wingate. His collections at the University of California Museum of Paleontology (Berkeley) consist of isolated vertebrae and other postcrania of phytosaurs and armor fragments of *Metoposaurus* (Hunt and Lucas, 1989).

The best preserved vertebrate fossil from the Bluewater Creek Member near Fort Wingate is the holotype partial skeleton of the aetosaur *Acompsosaurus wingatensis* Mehl, 1916. The type specimen of *Acompsosaurus* is now lost, so it must be evaluated from published illustrations. This specimen does not pertain to *Typothorax*, as suggested by Gregory (1953) (cf. Long and Ballew, 1985). The pelvis differs from that of *Desmatosuchus* in having a shorter, broad pubis and an ischium that apparently lacks a vertical supra-acetabular ridge. Instead, the pelvis of *Acompsosaurus* closely resembles that of *Stagonolepis robertsoni* (Walker, 1961, fig. 16). Therefore, we tentatively conclude that *Acompsosaurus wingatensis* is a species of *Stagonolepis*. The presence of *Stagonolepis* and *Metoposaurus* in the Bluewater Creek Member suggests it is of Carnian age (Hunt and Lucas, 1989).

Petrified Forest Member

The majority of the Chinle Formation in west-central New Mexico is encompassed by the Petrified Forest Member which is more than 300 m thick. Across this portion of the state, in all four Triassic terranes, we believe the threefold division of the Petrified Forest Member recognized in Arizona can be identified. Thus, the lower part of the Petrified Forest Member is bluish and purple, bentonitic mudstones overlain by the Sonsela Sandstone Bed below the reddish, mudstone- and siltstone-dominated upper portion of the Petrified Forest Member. In the Largo Creek terrane, however, only the upper part of the Petrified Forest Member crops out (Figs. 6, 7E). The underlying Sonsela Sandstone bed is exposed to the west, just across the Arizona–New Mexico line.

In the Zuni Pueblo terrane, the Petrified Forest Member is generally poorly exposed. However, the Sonsela Sandstone Bed can be recognized as light-gray to yellowish-brown, fine-grained to conglomeratic, crossbedded sandstone with thin lenses of bluish-gray to grayish-purple mudstone and siltstone (Anderson, 1987, 1989). It is as much as 43 m thick and is particularly well exposed at Ojo Caliente on the Zuni Indian Reservation (Fig. 7D).

The most extensive outcrops of the Petrified Forest Member in west-central New Mexico are in the Bluewater terrane. The lower part of the Petrified Forest Member here is relatively thin, 20–40 m thick (Figs. 6, 7C; Cooley, 1957, 1959a; Ash, 1969, 1978); the lower part of the Petrified Forest Member is more than 100 m thick at the Petrified Forest National Park in Arizona. In the Bluewater terrane, the lower part of the Petrified Forest Member is mostly grayish-purple, slightly silty, bentonitic mudstone with some nodular calcretes and lenticular, quartzose sandstone beds.

The Sonsela Sandstone Bed disconformably overlies the lower part of the Petrified Forest Member. In the Bluewater terrane, it is much the same lithology as in the Zuni Pueblo terrane—light-colored, fine-grained to conglomeratic, crossbedded sandstone with some fossil logs. The Sonela forms the prominent hogback between Fort Wingate and I-40 and the top of the northern dip-slope of the Zuni Mountains from Thoreau to Prewitt just south of I-40. Thickness of the Sonsela ranges from 15 to 61 m in this area (Cooley, 1957, 1959a; Repenning et al., 1969).

South of Fort Wingate, in a large toreva block of the Sonsela, we collected unionid bivalves at NMMNH locality 357. These bivalves (Fig. 9E–I) occur as a coquina bed (cf. Cooley, 1959a, p. 71) and are poorly preserved. Their shells have width-to-length ratios of 0.45–0.49 and thus resemble *Unio* sp. 1 and sp. 2 of Kues (1985). However, at present we only identify the Sonsela unionids as *Unio* sp.

The upper part of the Petrified Forest Member is poorly exposed in the Bluewater terrane. The most extensive outcrops are those around Thoreau in the northern half of T14N, R12, 13 and 14W. As much as 335 m thick near Thoreau (Repenning et al., 1969), the upper part of the Petrified Forest Member is dominated by banded grayish-red, pale reddish-brown and pale reddish-purple, mudstone, siltstone and sandy siltstone beds. To the west, between Fort Wingate and Red Rocks, the upper part of the Petrified Forest Member is only 244 m thick (Repenning et al., 1969).

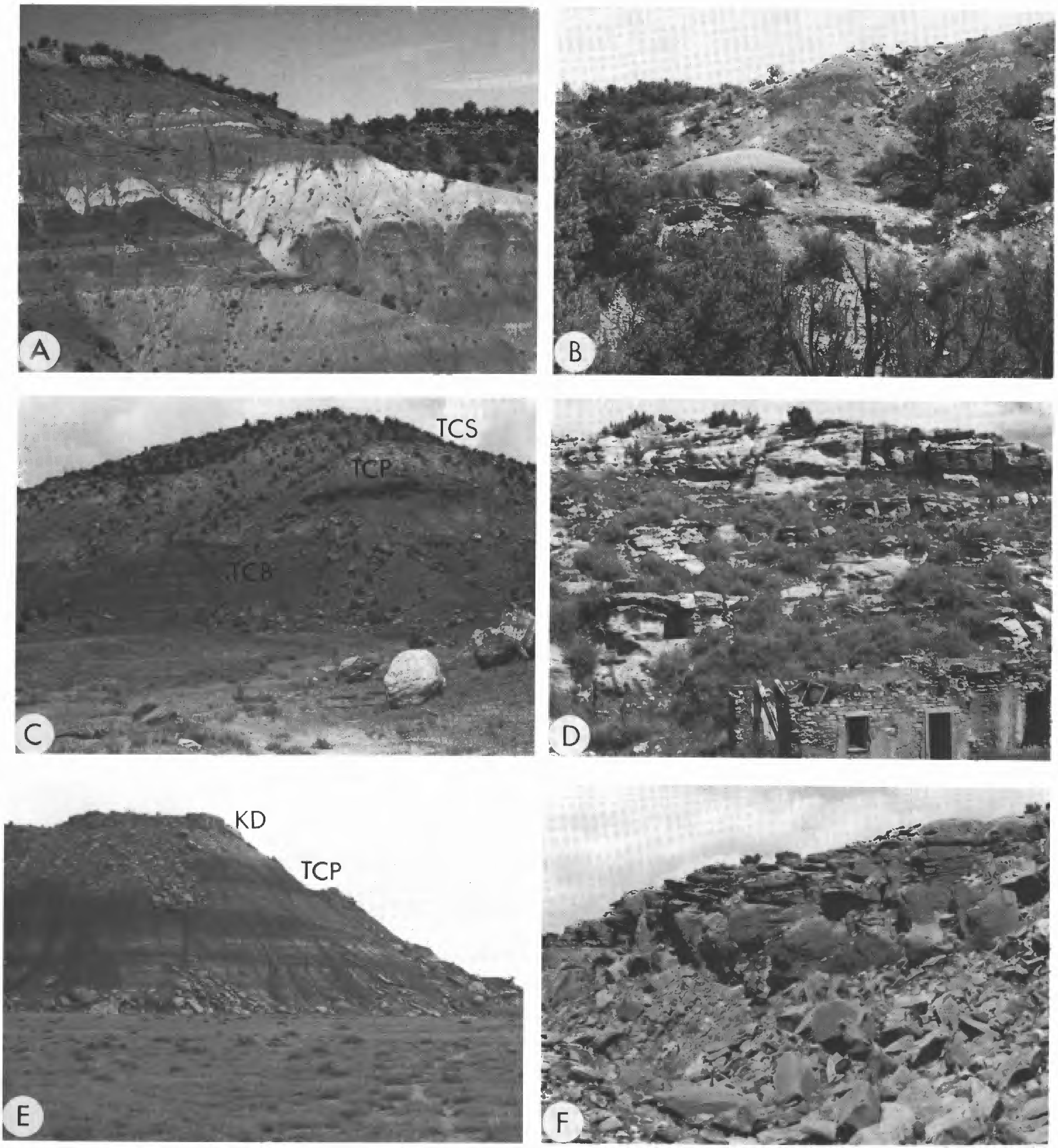

FIGURE 7. Photographs of Upper Triassic strata of the Chinle Formation in west-central New Mexico. A, Strata of the Bluewater Creek Member of the Chinle Formation cut by a Laramide? fault at Fort Wingate, NW$^{1}/_{4}$ NE$^{1}/_{4}$ sec. 16 (unsurveyed), T14N, R16W, McKinley County. B, Strata of the Bluewater Creek Member at the Ciniza pond locality, NE$^{1}/_{4}$ NW$^{1}/_{4}$ sec. 16 (unsurveyed), T14N, R16W, McKinley County. C, Type section of the Bluewater Creek Member (TCB) of the Chinle Formation, overlain by the lower Petrified Forest Member (TCP) and Sonsela Sandstone Bed (TCS). D, Sonsela Sandstone Bed of the Petrified Forest Member of the Chinle Formation at Ojo Caliente, SE$^{1}/_{4}$ SW$^{1}/_{4}$ sec. 17, T8N, R20W, McKinley County. E, Upper part of the Petrified Forest Member of the Chinle Formation (TCP) overlain by the Cretaceous Dakota Formation (KD) at Largo Creek, SW$^{1}/_{4}$ SE$^{1}/_{4}$ NE$^{1}/_{4}$ sec. 3, T3N, R19W, Catron County. F, Type section of the Correo Sandstone Bed, upper part of Petrified Forest Member of the Chinle Formation, at Mesa Gigante, NE$^{1}/_{4}$ NE$^{1}/_{4}$ SW$^{1}/_{4}$ sec. 20, T9N, R3W, Cibola County.

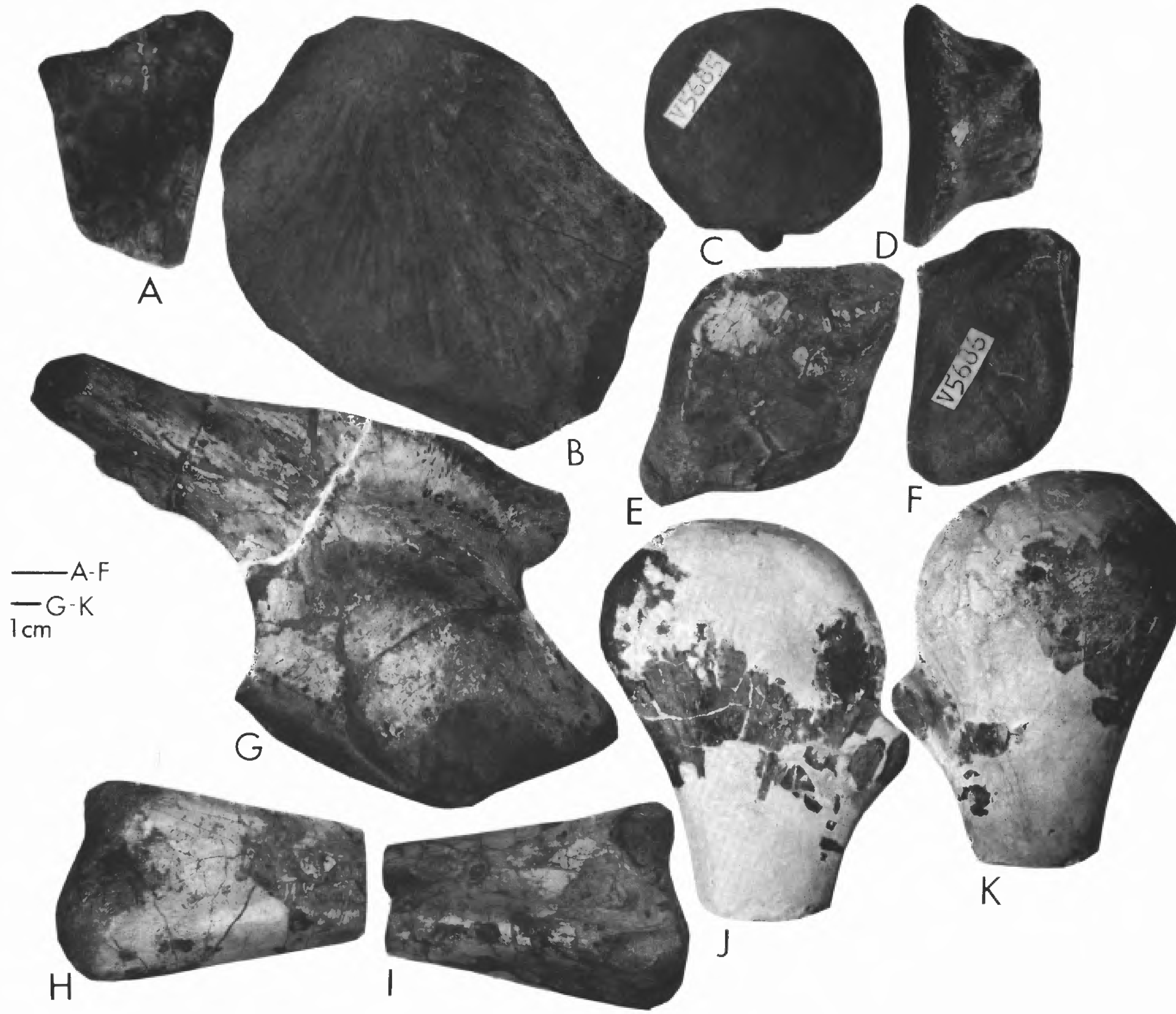

FIGURE 8. Some vertebrate fossils from the San Andres, Moenkopi and Chinle formations in west-central New Mexico. A, NMMNH P-10735, armor plate of a labyrinthodont amphibian from the San Andres Formation at NMMNH locality 355. B, MNA (Museum of Northern Arizona, Flagstaff) V5684, ventral view of interclavicle of a capitosauroid labyrinthodont from the Moenkopi Formation at NMMNH locality 360. C–D, MNA V5685, part of centrum of an archosaurian reptile, NMMNH locality 360. E–F, MNA V5686, part of centrum of an archosaurian reptile, NMMNH locality 360. G, FMNH (Field Museum of Natural History, Chicago) UC 1252, lateral view of left ilium of a phytosaur from the Bluewater Creek Member of the Chinle Formation at Fort Wingate. This specimen was identified as *Angistorhinus* and illustrated by Mehl et al. (1916, pl. 2). H–I, FMNH PR 1694, distal end of left femur of a phytosaur, anterior (H) and posterior (I) views, Bluewater Creek Member of Chinle Formation at Fort Wingate. J–K, FMNH PR 1694, proximal end of a right humerus of a phytosaur?, ventral (J) and dorsal (K) views, Bluewater Creek Member of Chinle Formation at Fort Wingate.

Near Thoreau, there are several prominent sandstone beds in the upper part of the Petrified Forest Member. These beds are composed of pale red and grayish-red, very fine- to medium-grained, quartzose, crossbedded sandstone. Cooley (1957) applied formal names (Chambers, Taaiylone, Zuni River and Perea) to beds like these in eastern Arizona and west-central New Mexico, but the names have not been used by subsequent workers.

The Correo Sandstone Bed of Kelley and Wood (1949) is a prominent sandstone bed in the upper part of the Petrified Forest Member in west-central New Mexico (Fig. 7F). Originally recognized by Kelley and Wood as the Correo Sandstone Member of the Chinle at Mesa Gigante (see Lucas et al., 1987 for a type section), the Correo is now considered a sandstone bed within mudrock of the upper part of the Petrified Forest Member (Stewart et al., 1972b; Lucas et al., 1987). It has been recognized as far east as the Hagan basin of Sandoval County (Lucas et al., 1988) and as far west as R12W just east of Thoreau (Schlee and Moench, 1963; Moench, 1964; Thaden and Ostling, 1967; Green and Pierson, 1971). This westward extension of the Correo, however, relies on a correlation first proposed by Smith (1954), who identified a sandstone bed near Thoreau 111 m below the top of the Chinle as Correo. If this correlation is correct, then pre-Entrada erosion must have removed more than 100 m of Chinle Formation above the Correo at Mesa Gigante. This correlation merits further study.

The Petrified Forest Member is present in the Mesa Lucero terrane, but we have undertaken little study of it. It represents most of the "red shale member" of the Chinle Formation of Kelley and Wood (1946).

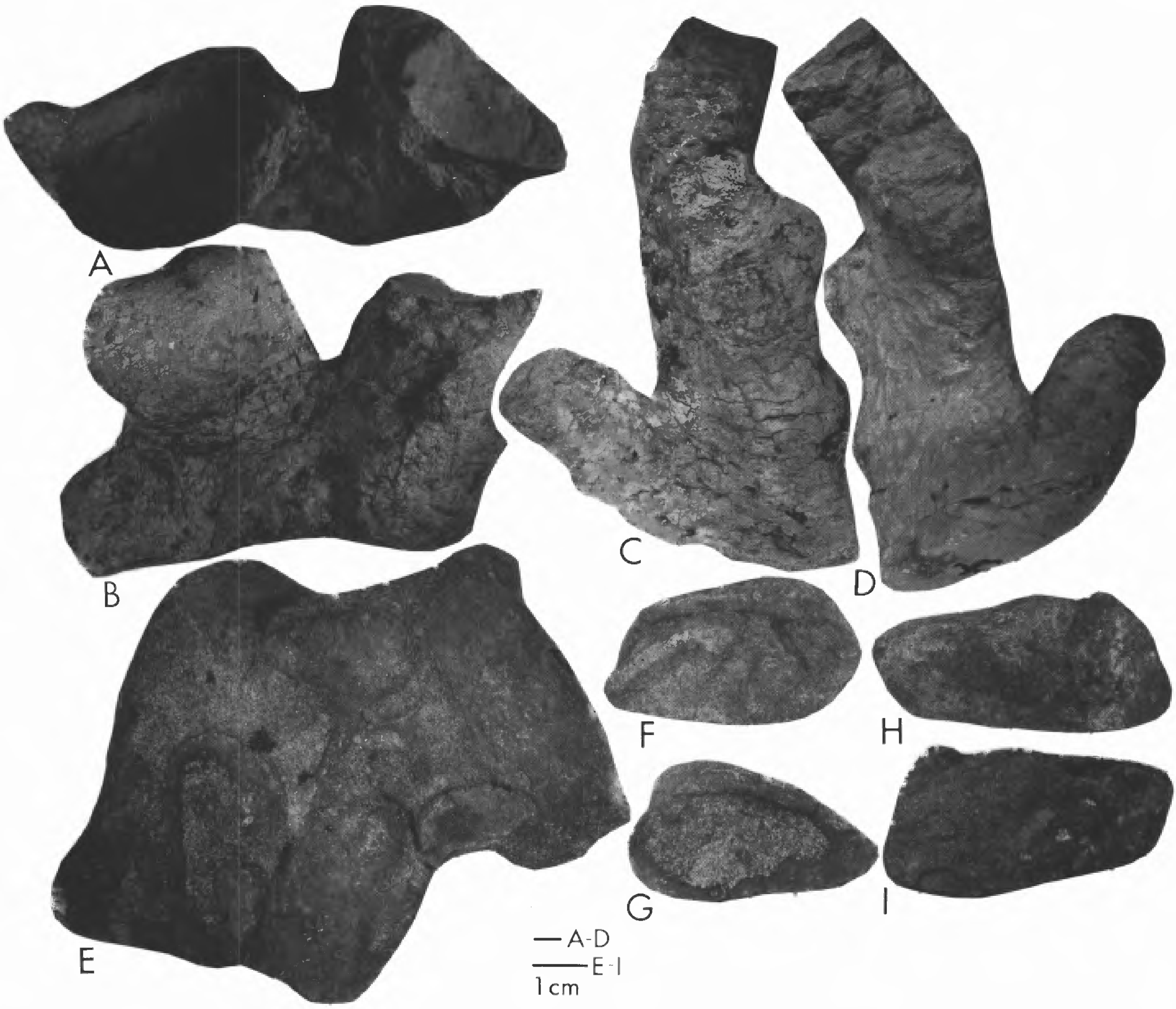

FIGURE 9. Some trace fossils and unionid bivalves from the Chinle Formation near Fort Wingate. A–B, NMMNH P-10736, root cast, superior (A) and lateral (B) views, NMMNH locality 358. C–D, NMMNH P-10737, root cast, lateral views, NMMNH locality 358. E—I, Unionidae from the Sonsela Sandstone Bed, NMMNH P-10738 (E), P-10739 (F), P-10740 (G), P-10741 (H–I), NMMNH locality 357.

In the terminology used by Tonking (1957, p. 15, pl. 1) and Jicha (1958, p. 19, pl. 1), the lower part of the Petrified Forest Member is at least the upper part of their "lower siltstone-shale unit." Whether this 100-m-thick unit includes strata of the Bluewater Creek Member will, as noted above, require further study. Jicha and Tonking's 61-m-thick "upper sandstone unit" clearly is the Sonsela Sandstone Bed, and their "upper siltstone-shale unit" (as much as 244 m thick) is the upper part of the Petrified Forest Member. Hunt et al. (1989) reported unionid bivalves and a vertebrate fauna of Carnian age from the lower part of the Petrified Forest Member near Mesa del Oro in secs. 11 and 15, T5N, R5W, Valencia County.

Owl Rock Member

The Owl Rock Member of the Chinle Formation conformably overlies the upper part of the Petrified Forest Member and is present, but very poorly exposed, in the Zuni Pueblo terrane north of the Zuni River (Cooley, 1957, 1959a; Repenning et al., 1969). In west-central New Mexico, the only well-developed exposures of the Owl Rock Member are in the Bluewater terrane, and it is absent in the Largo Creek and Mesa Lucero terranes.

At Red Rocks north of Fort Wingate, the Owl Rock Member is 24 m thick, and it is 15 m thick at Thoreau, the easternmost edge of its outcrop belt (Cooley, 1959). The most extensive Owl Rock outcrops in west-central New Mexico are in the Red Rocks (NE$^{1}/_{4}$, T15N, R17W) and Mount Powell–Thoreau (NE$^{1}/_{4}$, T14N, R14W and N$^{1}/_{2}$, T14N, R13W) areas. Typically, the Owl Rock Member is laterally persistent beds of pale-red and pale-reddish-brown, calcareous siltstone, thin-bedded sandy siltstone and light-greenish-gray limestone and nodular limestone. It is overlain disconformably by the Entrada Sandstone or the Rock Point Member of the Chinle Formation.

Rock Point Member

Since Harshbarger et al. (1957) named the Rock Point Member, it has been included in the Wingate Sandstone. However, as Stewart et al. (1972b, p. 43) noted, "the main lithologic type of the Rock Point Member, horizontally stratified siltstone, is more characteristic of the Chinle Formation." Indeed, Dubiel (1989) has now included the Rock Point Member in the Chinle Formation, a decision which we fully support.

In west-central New Mexico, the Rock Point Member is best exposed in the Zuni Pueblo terrane in the Zuni Buttes–Dowa Yalanne area (T10N, R19 and 20W). Here it is 37 m or more of pale to moderate-reddish-brown, interlayered fine-grained sandstone, sandy siltstone and silty mudstone that is flaggy to slabby bedded (e.g., Anderson, 1987, 1989).

The Rock Point Member is not present in the Largo Creek terrane, where the Cretaceous Dakota Formation rests directly on the upper part of the Petrified Forest Member. However, it is present in the Bluewater terrane where it is disconformably overlain by the Iyanbito Member (to the west) and medial silty member (to the east) of the Entrada Sandstone (e.g., Maxwell, 1982). Stewart et al.'s (1972b, p. 47) "unit of Bluewater Creek area," referred to as the "Red Sandstone Member" of the Chinle by Silver (1948, p. 73) is Entrada, as are strata in the Gallup-Grants area formerly termed Lukachukai Member of Wingate (Green, 1974).

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

SUPPOSED TRIASSIC STRATA

Here, we discuss two outcrops in west-central New Mexico earlier identified as Triassic but that we are certain are Permian.

Cottonwood Creek

Cooley (1959b) described as an "ancient cave deposit" strata in Cottonwood Creek, SW1/4 SW1/4 sec. 19, T13N, R13W, McKinley County. According to Cooley, this cave deposit is 10 m deep, lying below the San Andres–Moenkopi contact, and is part of the karst topography that developed in the Permian San Andres Formation prior to Moenkopi deposition.

We, however, are in agreement with S. Ash (oral commun., 1988) that these "cave" strata (Figs. 3, 10A) are part of a delta-plain facies of the uppermost San Andres Formation. Like Cooley (1959b), we see strata here as bedded shales, siltstones and sandstones above in-place limestone of the San Andres Formation. However, Cooley's (1959b, p. 89) "angular limestone fragments" in these strata are calcrete nodules, and his cave roof "formed by limestone blocks tightly bonded together by a calcareous cement" is a 1.5-m-thick layer of limestone with silicified crinoid debris. We identify this layer as the uppermost bed of the San Andres Formation; typical reddish-brown lithic wackestones of the Moenkopi Formation rest on it (Fig. 6).

The so-called "cave deposit" extends on strike for at least 1 km along Cottonwood Creek. According to S. Ash (oral commun., 1988), it can also be found in isolated outcrops as much as 2 km distant. Plant debris, an undiagnostic piece of labyrinthodont armor (Fig. 8A) and sandstone-bed geometry suggest a fluvial, probably delta-plain, origin

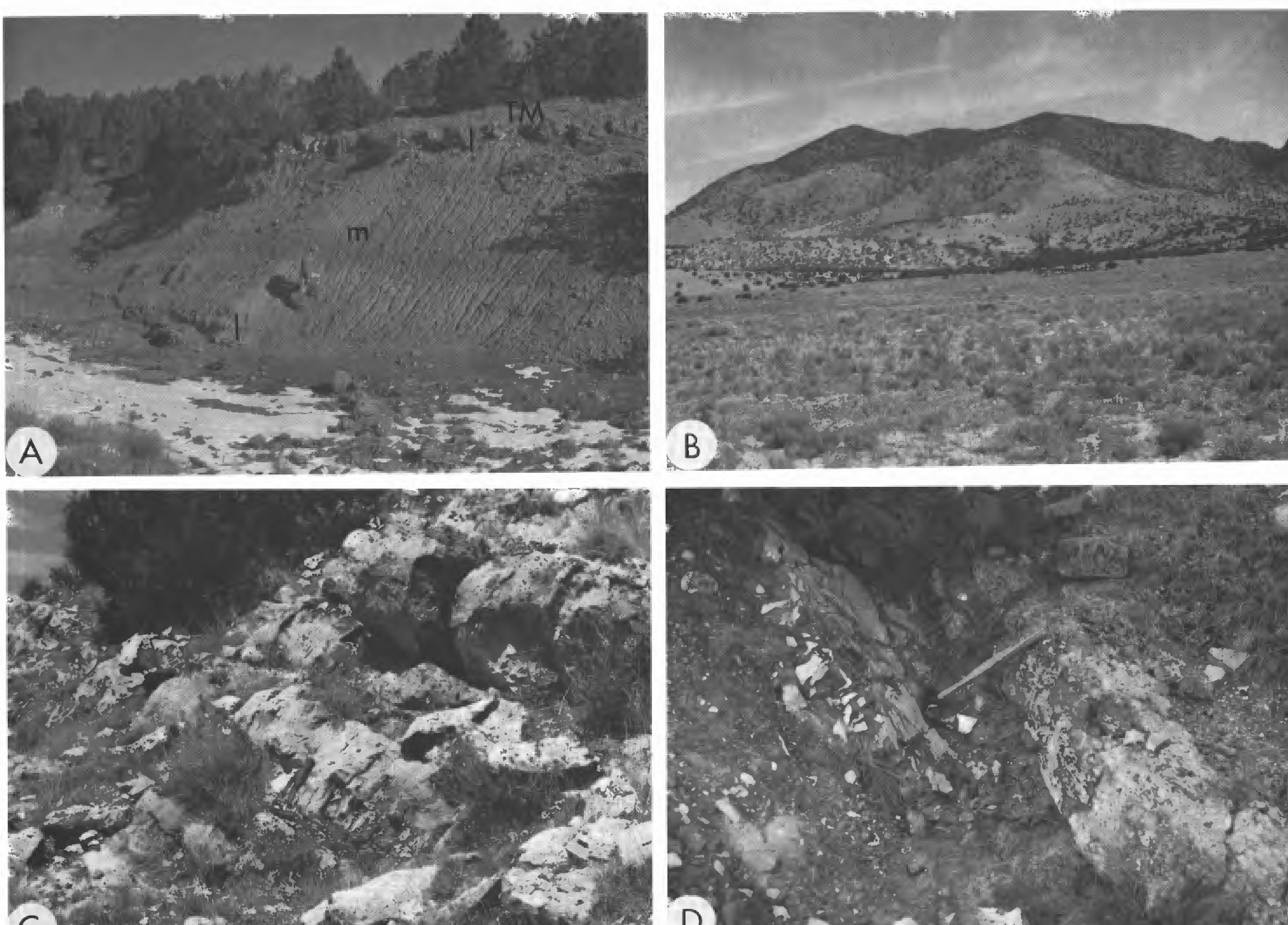

FIGURE 10. Some Permian strata in west-central New Mexico previously identified as Triassic. A, Strata of the San Andres Formation (l = limestone; sm = sandstone and mudrock; TM = Moenkopi Formation) in Cottonwood Creek that Cooley (1959b) identified as Moenkopi strata filling karst developed in the San Andres. B, Horse Mountain with hogback of San Andres Formation in front, NW1/4 sec. 20, T4S, R12W, Catron County. C, Close-up of San Andres strata at Horse Mountain. D, Fault gouge between San Andres and Yeso(?) formations at Horse Mountain.

for these strata which we include in the uppermost San Andres Formation.

Horse Mountain

Kottlowski and Foster (in Stearns, 1962) tentatively identified Triassic strata just south of Horse Mountain (sec. 20, T4S, R12W) in Catron County (Fig. 1). This identification formed the basis for the extensive Triassic outcrop near Horse Mountain depicted by Dane and Bachman (1965) on their geologic map of New Mexico. However, Willard and Stearns (1971) mapped these same strata as Permian.

Exposures are poor just south of Horse Mountain (Fig. 10B), but there is a prominent hogback of the San Andres Formation in the NW1/4 sec. 20, T4S, R12W that dips 35° to N10°W (Fig. 10C; Stearns, 1962). The San Andres here is mostly medium gray (N5) to light gray (N7), dolomitized micrite. Its uppermost bed is medium light-gray (N6), light-brownish-gray (5 YR 6/1) and yellowish-gray (5 Y 7/1) calcarenite, in part recrystallized to sparite and containing some dolomite rhombs. Overlying the San Andres to the north are the red beds that Kottlowski and Foster identified as "Triassic(?) sandstone." These trough-cross-bedded sandstones are of two types: (1) grayish-pink (5 R 8/2), fine-grained, silica- and calcite-cemented, hematitic quartzarenites; and (2) moderate-pink (5 R 7/4) to grayish-pink (5 R 8/2), very fine-grained, siliceous quartzwackes with mottling and liesegang banding. The only pebbly beds we located here are fault gouge (Fig. 10D) that is limestone and sandstone clasts cemented together by euhedral calcite crystals, hematite stained and mottled light red (5 R 6/6), grayish pink (5 R 8/2), light olive-gray (5 Y 6/1) and light brownish gray (5 YR 6/1).

None of these strata closely resemble Triassic strata in west-central New Mexico. Instead, the colors, mineralogy and texture of the red-bed sandstones at Horse Mountain are more reminiscent of the Permian Yeso Formation. This suggests that the red beds "above" the San Andres Formation actually are in fault contact with it, a possibility difficult to evaluate given the poor exposures in this area. We did not locate the silica-pebble conglomerates reported by Kottlowski and Foster (Stearns, 1962, p. 40), so the remote possibility exists that a very small, faulted slice of Triassic (or Tertiary Baca Formation?) is present at Horse Mountain. However, we know of no evidence of Triassic strata here, and, even if they are present, the outcrop is so small that it should not have appeared on a 1:500,000-scale map like that of Dane and Bachman (1965).

ACKNOWLEDGMENTS

We thank the following people and organizations for making this paper possible: B. Allen, O. Anderson, S. Ash, L. Chino, R. Dubiel, A. Hunt, B. Kues, J. Lorenz, K. Martini, New Mexico Museum of Natural History, P. Sealey, T. Williamson and Zuni Pueblo.

REFERENCES

Akers, J. P., Cooley, M. E. and Repenning, C. A., 1958, Moenkopi and Chinle formations of Black Mesa and adjacent areas: New Mexico Geological Society, Guidebook 9, p. 88–94.

Anderson, O. J., 1987, Geology and coal resources of Atarque Lake 1:50,000 quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Geologic Map 61, 2 sheets.

Anderson, O. J., 1989, Geology and mineral resources of Jones Ranch School quadrangle, McKinley County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Geologic Map 65, scale 1:24,000.

Ash, S. R., 1967, The Chinle (Upper Triassic) megaflora of the Zuni Mountains, New Mexico: New Mexico Geological Society, Guidebook 18, p. 125–131.

Ash, S. R., 1969, Ferns from the Chinle Formation (Upper Triassic) in the Fort Wingate area, New Mexico: U.S. Geological Survey, Professional Paper 613-D, 50 p.

Ash, S. R., editor, 1978, Geology, paleontology, and paleoecology of a Late Triassic lake, western New Mexico: Brigham Young University, Geology Studies, v. 25 (2), 95 p.

Ash, S. R., 1980, Upper Triassic floral zones of North America; *in* Dilcher, D. L. and Taylor, T. N., eds., Biostratigraphy of fossil plants: Stroudsburg, Pa., Dowden, Hutchinson and Ross, Inc., p. 153–170.

Ash, S. R., 1989, The Upper Triassic Chinle flora of the Zuni Mountains, New Mexico: New Mexico Geological Society, Guidebook 40.

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

Bates, R. L., 1942, The oil and gas resources of New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 18, p. 83–140.

Bilodeau, W. L., 1986, Mesozoic Mogollon highland and Early Cretaceous rift basin in southeastern Arizona: Journal of Geology, v. 94, p. 734–746.

Blakey, R. C. and Gubitosa, R., 1984, Controls on sandstone body geometry and architecture in the Chinle Formation (Upper Triassic), Colorado Plateau: Sedimentary Geology, v. 38, p. 51–86.

Camp, C. L., 1930, A study of phytosaurs, with description of new material from western North America: Memoirs of the University of California 10, 161 p.

Collinson, J. D. and Thompson, D. B., 1982, Sedimentary structures. London, George Allen and Unwin, 194 p.

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

Cooley, M. E., 1958, The Mesa Redondo Member of the Chinle Formation, Apache and Navajo counties, Arizona: Plateau, v. 31, p. 7–15.

Cooley, M. E., 1959a, Triassic stratigraphy in the state line region of west-central New Mexico and east-central Arizona: New Mexico Geological Society, Guidebook 10, p. 66–73.

Cooley, M. E., 1959b, Ancient cave deposit near Thoreau, New Mexico: Plateau, v. 31, p. 89.

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

Darton, N. H., 1910, A reconnaissance of parts of northwestern New Mexico and northern Arizona: U.S. Geological Survey, Bulletin 435, 88 p.

Darton, N. H., 1928, "Red beds" and associated formations in New Mexico: U.S. Geological Survey, Bulletin 794, 356 p.

Daugherty, L. H., 1941, The Upper Triassic flora of Arizona: Carnegie Institution of Washington, Publication 526, 108 p.

Dubiel, R. F., 1989, Sedimentology and revised nomenclature for the upper part of the Upper Triassic Chinle Formation and the Lower Jurassic Wingate Sandstone, northwestern New Mexico and northeastern Arizona: New Mexico Geological Society, Guidebook 40.

Dubiel, R. F., Blodgett, R. H. and Bown, T. M., 1987, Lungfish burrows in the Upper Triassic Chinle and Dolores formations, Colorado Plateau: Journal of Sedimentary Petrology, v. 57, p. 512–521.

Dubiel, R. F., Blodgett, R. H. and Bown, T. M., 1988, Lungfish burrows in the Upper Triassic Chinle and Dolores formations, Colorado Plateau—reply: Journal of Sedimentary Petrology, v. 58, p. 367–369.

Dutton, C. E., 1885, Mount Taylor and the Zuni Plateau: U.S. Geological Survey, Sixth Annual Report, p. 105–198.

Friend, P. F., Slater, M. J. and Williams, R. C., 1979, Vertical and lateral building of river sandstone bodies, Ebro basin, Spain: Journal of the Geological Society of London, v. 136, p. 39–46.

Gilbert, G. K., 1875, Report upon the geology of portions of Nevada, Utah, California, and Arizona: U.S. Geological and Geographical Surveys West of the 100th Meridian [Wheeler], v. 3, p. 17–187.

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.

Green, M. W., 1974, The Iyanbito Member (a new stratigraphic unit) of the Jurassic Entrada Sandstone: U.S. Geological Survey, Bulletin 1395-D, 12 p.

Green, M. W. and Pierson, C. T., 1971, Geologic map of the Thoreau NE quadrangle, McKinley County, New Mexico: U.S. Geological Survey, Map GQ-954, scale 1:24,000.

Gregory, H. E., 1915, The igneous origin of the "glacial deposits" on the Navajo Reservation: American Journal of Science (4), v. 40, p. 97–115.

Gregory, H. E., 1917, Geology of the Navajo Country: a reconnaissance of parts of Arizona, New Mexico, and Utah: U.S. Geological Survey, Professional Paper 93, 161 p.

Gregory, J. T., 1953, *Typothorax* and *Desmatosuchus*: Postilla, no. 17, 27 p.

Harshbarger, J. W., Repenning, C. A. and Irwin, J. H., 1957, Stratigraphy of the uppermost Triassic and the Jurassic rocks of the Navajo country: U.S. Geological Survey, Professional Paper 291, 74 p.

Hayden, S. N. and Lucas, S. G., 1988a, Stratigraphy of the Middle Triassic Moenkopi Formation, Lucero uplift, west-central New Mexico: New Mexico Geology, v. 10, p. 67.

Hayden, S. N. and Lucas, S. G., 1988b, Stratigraphy of the Permo-Triassic boundary in northern New Mexico: Abstracts of the Symposium on Southwestern Geology and Paleontology 1988 [Museum of Northern Arizona, Flagstaff], p. 5.

Hayden, S. N. and Lucas, S. G., 1989, Stratigraphy of the Triassic Moenkopi

Formation, west-central New Mexico: New Mexico Geological Society, Guidebook 40.
Hunt, A. P. and Lucas, S. G., 1989, Late Triassic vertebrate localities in New Mexico; *in* Lucas, S. G. and Hunt, A. P., eds., Dawn of the age of dinosaurs in the American Southwest: Albuquerque, New Mexico Museum of Natural History, p. 72–101.
Hunt, A. P., Lucas, S. G., Martini, K. and Martini, T., 1989, Triassic stratigraphy and paleontology, Mesa del Oro, Valencia County, New Mexico: New Mexico Geological Society, Guidebook 40.
Jicha, H. L., Jr., 1958, Geology and mineral resources of Mesa del Oro quadrangle, Socorro and Valencia counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 56, 67 p.
Kelley, V. C. and Wood, G. H., 1946, Lucero uplift, Valencia, Socorro, and Bernalillo counties, New Mexico: U.S. Geological Survey, Oil and Gas Investigations Preliminary Map OM-47.
Kietzke, K. K., 1988, The calcareous microfauna of the Moenkopi Formation (Triassic, Scythian or Anisian) of central New Mexico: New Mexico Geology, v. 10, p. 64–65.
Kietzke, K. K., 1989a, 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.
Kietzke, K. K., 1989b, Calcareous microfossils from the Moenkopi Formation (Triassic, Scythian or Anisian) of central New Mexico: New Mexico Geological Society, Guidebook 40.
Klappa, C. F., 1980, Rhizoliths in terrestrial carbonates: classification, recognition, genesis and significance: Sedimentology, v. 27, p. 613–629.
Kues, B. S., 1985, Nonmarine molluscs from the Chinle Formation, Dockum Group (Upper Triassic), of Bull Canyon, Guadalupe County, New Mexico: New Mexico Geological Society, Guidebook 36, p. 185–196.
Kues, B. S. and Lucas, S. G., 1989, Stratigraphy and paleontology of a San Andres Formation (Permian, Leonardian) outlier, Zuni Indian Reservation, New Mexico: New Mexico Geological Society, Guidebook 40.
Long, R. A. and Ballew, K. L., 1985, Aetosaur dermal armor from the Late Triassic of southwestern North America, with special reference to material from the Chinle Formation of Petrified Forest National Park: Museum of Northern Arizona, Bulletin 54, p. 35–68.
Lucas, S. G., Allen, B. D. and Hayden, S. N., 1987, Type section of the Triassic Correo Sandstone Bed, Chinle Formation, Cibola County, New Mexico: New Mexico Journal of Science, v. 27, p. 87–93.
Lucas, S. G., Martini, K. and Martini, T., 1988, Upper Triassic Correo Sandstone Bed, Petrified Forest Member, Chinle Formation, Hagan basin, Sandoval County, New Mexico: New Mexico Geology, v. 10, p. 65.
Marcou, J., 1856, Résumé of a geological reconnaissance extending from Napoleon at the junction of the Arkansas with the Mississippi, to the Pueblo de Los Angeles in California: U.S. Pacific Railroad Explorations, v. 3, pt. 4, p. 165–171.
Marcou, J., 1858, Geology of North America with two reports on the prairies of Arkansas and Texas, the Rocky Mountains of New Mexico, and the Sierra Nevada of California, originally made for the United States Government. Zurich, Zürcher and Furrer, 144 p.
Maxwell, C. H., 1982, Mesozoic stratigraphy of the Laguna-Grants region: New Mexico Geological Society, Guidebook 33, p. 261–266.
Maxwell, C. H., 1988a, Geologic map of the Cerro del Oro quadrangle, Cibola County, New Mexico: U.S. Geological Survey, Miscellaneous Field Studies Map MF-2033, scale 1:24,000.
Maxwell, C. H., 1988b, Geologic map of the Marmon Ranch quadrangle, Cibola County, New Mexico: U.S. Geological Survey, Miscellaneous Field Studies, Map MF-2049, scale 1:24,000.
McAllister, J. A., 1988, Lungfish burrows in the Upper Triassic Chinle and Dolores formations, Colorado Plateau—comments on the recognition criteria of fossil lungfish burrows: Journal of Sedimentary Petrology, v. 58, p. 365–369.
McKee, E. D., 1951, Sedimentary basins of Arizona and adjoining areas: Geological Society of America Bulletin, v. 62, p. 481–506.
McKee, E. D., 1954, Stratigraphy and history of the Moenkopi Formation of Triassic age: Geological Society of America, Memoir 61, 133 p.
Mehl, M. G., Toepelman, W. C. and Schwartz, G. M., 1916, New or little known reptiles from the Trias of Arizona and New Mexico with notes on the fossil bearing horizons near Wingate, New Mexico: Bulletin of the University of Oklahoma (new series), no. 103, 44 p.
Miall, A. D., 1984, Principles of sedimentary basin analysis. New York, Springer-Verlag, 490 p.
Moench, R. H., 1964, Geology of the Dough Mountain quadrangle New Mexico: U.S. Geological Survey Map GQ-354, scale 1:24,000.
Momper, J. A., 1957, Pre-Morrison stratigraphy of the southern and western San Juan Basin: Four Corners Geological Society, Guidebook 2, p. 85–94.
Newberry, J. S., 1861, Geological report; *in* Ives, J. C., Report upon the Colorado River of the West: U.S. 36th Congress, 1st Session, Senate Executive Document and House Executive Document 90, pt. 3, 154 p.
Newberry, J. S., 1876, Geological report; *in* Macomb, J. N., Report of the exploring expedition from Santa Fe, New Mexico, to the junction of the Grand and Green Rivers of the Great Colorado River of the West, in 1859, under the command of Capt. J. N. Macomb: U.S. Army, Engineer Department, p. 101–109.
Peabody, F. E., 1948, Reptile and amphibian trackways from the Lower Triassic Moenkopi Formation of Arizona and Utah: University of California Publications, Bulletin of the Department of Geological Sciences, v. 27, p. 295–468.
Repenning, C. A., Cooley, M. F. and Akers, J. P., 1969, Stratigraphy of the Chinle and Moenkopi formations, Navajo and Hopi Indian reservations Arizona, New Mexico, and Utah: U.S. Geological Survey, Professional Paper 521-B, 34 p.
Schlee, J. S. and Moench, R. H., 1963, Geologic map of the Mesita quadrangle New Mexico: U.S. Geological Survey Map GQ-210, scale 1:24,000.
Silver, C., 1948, Jurassic overlap in western New Mexico: American Association of Petroleum Geologists Bulletin, v. 32, p. 68–81.
Smith, C. T., 1954, Geology of the Thoreau quadrangle, McKinley and Valencia counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 31, 36 p.
Smith, C. T., 1957, Geology of the Zuni Mountains, Valencia and McKinley counties, New Mexico: Four Corners Geological Society, Guidebook 2, p. 53–61.
Stearns, C. E., 1962, Geology of the north half of the Pelona quadrangle, Catron County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 78, 46 p.
Stewart, J. H., 1957, Proposed nomenclature of part of Upper Triassic strata in southeastern Utah: American Association of Petroleum Geologists Bulletin, v. 1, p. 441–465.
Stewart, J. H., Poole, F. G. and Wilson, R. F., 1972a, Changes in nomenclature of the Chinle Formation on the southern part of the Colorado Plateau: 1850s–1950s: Museum of Northern Arizona Bulletin 47, p. 75–103.
Stewart, J. H., Poole, F. G. and Wilson, R. F., 1972b, 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.
Stewart, J. H., Poole, F. G. and Wilson, R. F., 1972c, Stratigraphy and origin of the Triassic Moenkopi Formation and related strata in the Colorado Plateau region: U.S. Geological Survey, Professional Paper 691, 195 p.
Talmadge, S. B. and Wooton, T. P., 1937, The nonmetallic mineral resources of New Mexico and their economic features (exclusive of fuels): New Mexico School of Mines, Bulletin 12, 159 p.
Thaden, R. E. and Ostling, E. J., 1967, Geologic map of the Bluewater quadrangle Valencia and McKinley counties, New Mexico: U.S. Geological Survey Map GQ-679, scale 1:24,000.
Tonking, W. H., 1957, Geology of Puertecito quadrangle, Socorro County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 41, 67 p.
Tucker, M. E., 1982, The field description of sedimentary rocks [Geological Society of London Handbook]. Milton Keynes, The Open University Press, 112 p.
Walker, A. D., 1961, Triassic reptiles from the Elgin area: *Stagonolepis, Dasygnathus* and their allies: Philosophical Transactions of the Royal Society of London (B), v. 244, p. 103–204.
Ward, L. F., 1901, Geology of the Little Colorado Valley: American Journal of Science (4), v. 12, p. 401–413.
Willard, M. E. and Stearns, C. E., 1971, Reconnaissance geologic map of the Pelona thirty-minute quadrangle: New Mexico Bureau of Mines and Mineral Resources, Geologic Map 23, scale 1:126,720.
Williams, G. H., Turner, F. J. and Gilbert, G. M., 1982, Petrography (2nd ed.). San Francisco, W. H. Freeman and Company, 344 p.

APPENDIX 1—STRATIGRAPHIC SECTIONS

The stratigraphic sections in Figures 3 and 6 are described here. These sections were measured with a Brunton pocket transit, a 1.5-m staff and a measuring tape. Rock colors are those of Goddard et al. (1984).

Section WR-1

NW¼ NE¼ NE¼ sec. 36, T7N, R4W; White Ridge quadrangle, Valencia County, New Mexico; measured 9 July 1987, by S. N. Hayden.

unit	lithology	thickness (m)
	Moenkopi Formation:	
8	Sandstone (lithic wackestone), pale red (5 R 6/2 and 10 R 6/2), grayish red (5 R 4/2), moderate reddish orange (10 R 6/6) and grayish red (10 R 4/2); abundant trough and planar crossbedding; channel scours with intraformational conglomerate at base containing clay- and silt-pebble clasts and bone fragments; sand is from 500 μm to silt, and consists of quartz, chert, opaques, mica and lithic rock fragments and is very angular to subrounded; cementation is dominated by intrasparite calcite, with minor silica overgrowths on quartz grains.	3.4
7	Siltstone/claystone with lenses of very calcareous sandstone; silt/clay is moderate orange-pink (10 R 7/4) and pale red (5 R 6/2 and 10 R 6/2); sand is light brown (5 YR 6/4), pale yellowish brown (10 YR 6/2), pale yellowish orange (10 YR 7/4) and light olive-gray (5 Y 6/1); sands have scour bases with rip-up clasts, are 0.1 to 0.2 m thick by 1.0 to 1.5 m wide and contain bone fragments; sand is mostly quartz and calcite, is angular to subrounded and generally less than 700 μm in size; siltstone is rippled in thin laminae, whereas the clay-dominated mudstone is massive; entire unit is very calcareous.	15.3
6	Sandstone (lithic wackestone), grayish red (10 R 4/2), pale reddish brown (10 R 5/4) and moderate reddish orange (10 R 6/6); weathers to moderate yellowish brown (10 YR 5/4), dusky yellowish brown (10 YR 2/2) and brownish black (10 YR 2/1); trough crossbedded, ripple laminated and massive with bioturbation and mottling; clay- and silt-pebble intraformational conglomerates are present on channel scours; sand is quartz, chert, siltstone and limestone lithic fragments with accessory micas and opaques from 250 μm to silt and is angular to subrounded; forms a cliff.	2.0
5	Siltstone; same colors and lithology as unit 3.	6.7
4	Sandstone (lithic wackestone), pale red (10 R 6/2), pale brown (5 YR 5/2), moderate orange-pink (5 YR 8/4) and light brown (5 Y 6/4); rippled to small trough crossbedded in thin laminae to 10-cm-thick beds; contains small channel scours as much as 0.25 m thick; sand from 150 μm to silt consisting of quartz, siltstone, chert and opaques; poorly sorted; very angular to subrounded; cementation is by intrasparite calcite with fine silt in matrix making up 30% of rock.	0.9
3	Siltstone; moderate reddish orange (10 R 6/6) and moderate reddish brown (10 R 4/6) with pale greenish yellow (10 Y 8/2) and moderate orange-pink (5 YR 8/4) mottling; thinly laminated to nodular to massive; bioturbated; some starved ripple-silt deposits in muds; dominantly fissile and calcareous.	1.2
2	Siltstone/claystone; moderate yellow (5 Y 7/6), dark yellowish orange (10 YR 6/6), very light gray (N8), yellowish gray (5 Y 8/1) and very pale orange (10 YR 8/2); thinly bedded to nodular; very slightly calcareous; minor very fine sand to 100 μm.	0.9
	Thickness of Moenkopi Formation:	30.4 m
	Disconformity	
	San Andres Formation:	
1	Limestone with goethite on weathered surface; dark yellowish orange (10 YR 6/6), grayish orange (10 YR 7/4), light brown (5 YR 6/4), moderate orange-pink (5 YR 8/4), and dark yellowish brown (10 YR 4/2); beds are massive limestones, 0.5 to 1.5 m thick, with approximately 5 m exposed locally by arroyo cuts.	not measured

Section WR-2

NE¼ NW¼ NE¼ sec. 36 and SE¼ SW¼ SE¼ sec. 25, T7N, R4W, White Ridge quadrangle, Valencia County, New Mexico; measured 9 July 1987, by S. N. Hayden.

unit	lithology	thickness (m)
	Quaternary spring deposits:	
12	Limestone	not measured
	Moenkopi Formation:	
11	Sandstone (lithic wackestone), pale red (5 R 6/2), pale red (10 R 6/2), grayish red (5 R 4/2), moderate reddish orange (10 R 6/6) and grayish red (10 R 4/2); abundant trough and planar crossbedding; sand is from 500 μm to silt, and consists of quartz, chert, opaques, mica and lithic rock fragments; very angular to subrounded; cementation is dominantly by intrasparite calcite, with minor silica overgrowths on quartz grains.	1.2
10	Siltstone/claystone with lenses of very calcareous sandstone; silt/clay is moderate orange-pink (10 R 7/4) and pale red (5 R 6/2 and 10 R 6/2); sand is light brown (5 YR 6/4), pale yellowish brown (10 YR 6/2), pale yellowish orange (10 YR 7/4) and light olive-gray (5 Y 6/1); sands have scour bases with rip-up clasts and are 0.1 to 0.2 m thick by 1.0 to 1.5 m wide; sand is mostly quartz and calcite, and is angular to subrounded, generally less than 350 μm in size; siltstone is rippled in thin laminae while the clay-dominated mudstone is massive; entire unit is very calcareous and contains nodular limestone.	2.2
9	Sandstone (lithic wackestone), grayish red (10 R 4/2), pale reddish brown (10 R 5/4) and moderate reddish orange (10 R 6/6), weathers to moderate yellowish brown (10 YR 5/4), dusky yellowish brown (10 YR 2/2) and brownish black (10 YR 2/1); trough crossbedded to ripple laminated to massive with bioturbation and mottling; clay- and silt-pebble intraformational conglomerates are present on channel scours, which are as much as 1.8 m deep; sand is quartz, chert, siltstone and limestone lithic fragments with accessory micas and opaques from 250 μm to silt and is angular to subrounded; forms prominent cliff.	3.8
8	Mudstone; same color and lithology as unit 6.	14.5
7	Siltstone; moderate reddish brown (10 R 4/6) and pale reddish brown (10 R 5/4), weathers to grayish red (10 R 4/2); ripple laminar to small trough crossbeds, reactivation surfaces every 0.3 to 0.4 m.	1.8
6	Mudstone; moderate reddish orange (10 R 6/6) and moderate reddish brown (10 R 4/6) with pale greenish yellow (10 Y 8/2) and moderate orange-pink (5 YR 8/4) mottling; thinly laminated to nodular to massive, dominantly fissile and calcareous.	2.2
5	Sandstone (lithic wackestone), brownish gray (5 YR 4/1) and grayish red-purple (5 RP 4/2), weathers to dark reddish brown (10 R 3/4) and very dusky red (10 R 2/2); parallel laminated to planar foresets with some fine, sinuous crested to linguoid ripple marks; sand is from 125 μm to silt, and consists of quartz, siltstone, chert and opaques; immature; cementation is by intrasparite calcite with fine silt in matrix making up 30% of rock; ledge former.	0.6
4	Siltstone to muddy siltstone; moderate reddish brown (10 R 4/6); finely laminated with sinuous crested ripple marks; fissile; calcareous.	1.8
3	Siltstone/sandstone; moderate yellow (5 Y 7/6), very light gray (N8) and yellowish gray (5 Y 8/1); thinly bedded to nodular; very slightly calcareous; very fine sand to 125 μm silt is massive to fissile and parallel laminated.	1.5
2	Siltstone/claystone; moderate yellow (5 Y 7/6), dark yellowish orange (10 YR 6/6), very light gray (N8), yellowish gray (5 Y 8/1) and very pale orange (10 YR 8/2); thinly bedded to nodular; noncalcareous; minor very fine sand to 100 μm.	0.3
	Thickness of Moenkopi Formation:	29.9+ m

Disconformity

San Andres Formation:

unit	lithology	thickness (m)
1	Limestone with goethite on weathered surface; dark yellowish orange (10 YR 6/6), grayish orange (10 YR 7/4), light brown (5 YR 6/4), moderate orange-pink (5 YR 8/4) and dark yellowish brown (10 YR 4/2); beds are massive limestones.	not measured

Section WR-3

SE¼ NW¼ NW¼ sec. 36, T7N, R4W, White Ridge quadrangle, Valencia County, New Mexico; measured 10 July 1987, by S. N. Hayden.

unit	lithology	thickness (m)
	Moenkopi Formation:	
15	Sandstone; same lithology and colors as unit 13.	2.6
14	Mudstone; same lithology and colors as unit 10.	1.2
13	Sandstone (lithic wackestone), pale red (5 R 6/2 and 10 R 6/2), grayish red (5 R 4/2), moderate reddish orange (10 R 6/6) and grayish red (10 R 4/2); abundant trough and planar crossbedding; sand is from 500 μm to silt; consists of quartz, chert, opaques, mica and lithic rock fragments and is very angular to subrounded; cementation is dominantly by intrasparite calcite, with minor silica overgrowths on quartz grains.	1.8
12	Mudstone; same lithology and colors as unit 10.	4.6
11	Sandstone (lithic wackestone), grayish red (10 R 4/2), pale reddish brown (10 R 5/4) and moderate reddish orange (10 R 6/6), weathers to grayish red (10 R 4/2) and brownish black (10 YR 2/1); trough crossbedded to ripple laminated; clay-and-silt pebble intraformational conglomerates are present on channel scours, which are as much as 1.2 m deep and 30 m wide; sand is quartz, chert, siltstone and limestone lithic fragments with accessory micas and opaques from 250 μm to silt and is angular to subrounded; forms prominent ledge.	1.8
10	Mudstone; moderate reddish brown (10 R 4/6) and dark reddish brown (10 R 3/4); massive.	6.0
9	Sandstone; same lithology and colors as unit 7.	0.5
8	Siltstone; same lithology and colors as unit 6; with a lenticular sandstone like unit 7 which is 0.3 m thick and occurs 0.75 m above the base.	3.8
7	Sandstone (lithic wackestone), brownish gray (5 YR 4/1) and grayish red-purple (5 RP 4/2), weathers to dark reddish brown (10 R 3/4) and very dusky red (10 R 2/2); fine sinuous to linguoid ripple marks, with some channel scours; sand from 125 μm to silt consisting of quartz, siltstone, chert and opaques; poorly sorted; very angular to subrounded; cementation is by intrasparite calcite with fine silt in matrix making up 30% of rock.	0.3
6	Siltstone; moderate reddish orange (10 R 6/6) and moderate reddish brown (10 R 4/6), with pale greenish yellow (10 Y 8/2) to moderate orange-pink (5 YR 8/4) mottling; thinly laminated, nodular and massive; bioturbated; some starved-ripple silt deposition in muds; dominantly fissile and calcareous.	2.2
5	Siltstone; very light gray (N8) and yellowish gray (5 Y 8/1); thinly bedded, ripple to parallel laminated; slightly calcareous; some very fine sand to 125 μm.	1.5
4	Siltstone/sandstone; moderate yellow (5 Y 7/6), very light gray (N8) and yellowish gray (5 Y 8/1); thinly bedded to nodular; very slightly calcareous; very fine sand to 125 μm; silt is massive to fissile and parallel laminated.	1.5
3	Shale; white (N9) to very light gray (N8); thinly laminated and fissile.	0.5
2	Siltstone/claystone; moderate yellow (5 Y 7/6), dark yellowish orange (10 YR 6/6), very light gray (N8), yellowish gray (5 Y 8/1) and very pale orange (10 YR 8/2); thinly bedded to nodular, noncalcareous.	0.3
	Thickness of Moenkopi Formation:	27.9+ m
	Disconformity	
	San Andres Formation:	
1	Limestone with goethite on weathered surface; dark yellowish orange (10 YR 6/6), grayish orange (10 YR 7/4), light brown (5 YR 6/4), moderate orange-pink (5 YR 8/4) and dark yellowish brown (10 YR 4/2); beds are massive.	not measured

Section WR-4

SE¼ SE¼ SW¼ sec. 25, T7N, R4W, White Ridge quadrangle, Valencia County, New Mexico; measured 10 July 1987, by S. N. Hayden. Unit 8 of this section is observably continuous with section WR-3, unit 11; above this point not measured.

unit	lithology	thickness (m)
8	Sandstone (lithic wackestone), grayish red (10 R 4/2), pale reddish brown (10 R 5/4) and moderate reddish orange (10 R 6/6), weathers to grayish red (10 R 4/2) and brownish black (10 YR 2/1); trough crossbedded to ripple laminated; clay-and-silt pebble intraformational conglomerates are present on channel scours; sand is quartz, chert, siltstone and limestone lithic fragments with accessory micas and opaques from 250 μm to silt and is angular to subrounded; forms a cliff.	1.6
7	Siltstone/mudstone; moderate reddish orange (10 R 6/6) and moderate reddish brown (10 R 4/6) with pale greenish yellow (10 Y 8/2) and moderate orange-pink (5 YR 8/4) mottling; thinly laminated to nodular and massive; bioturbated; some starved-ripple silt deposition in muds, dominantly fissile and calcareous.	6.7
6	Sandstone; same lithology and colors as unit 4.	0.6
5	Siltstone; same lithology and colors as unit 3.	4.0
4	Sandstone (lithic wackestone), brownish gray (5 YR 4/1) and grayish red-purple (5 RP 4/2), weathers to dark reddish brown (10 R 3/4) and very dusky red (10 R 2/2), fine ripple marks, scours; bioturbated on bedding planes; sand from 150 μm to silt consists of quartz, siltstone, chert and opaques: poorly sorted, very angular to subrounded; cementation is by intrasparite calcite with fine silt in matrix making up 30% of rock.	0.3
3	Siltstone; moderate reddish orange (10 R 6/6) and moderate reddish brown (10 R 4/6), with pale greenish yellow (10 Y 8/2) and moderate orange-pink (5 YR 8/4) mottling; thinly laminated to nodular to massive; bioturbated; some starved-ripple silt deposition in muds; dominantly fissile and calcareous.	1.0
2	Sandstone; moderate yellow (5 Y 7/6), very light gray (N8) and yellowish gray (5 Y 8/1); thinly to thickly bedded; sand to 750 μm; conglomerate at base contains rip-up clasts of San Andres limestone and yellow siltstone like unit 1 below; complex ribbon type sandstone is exposed intermittently by modern arroyo erosion for several hundred meters; very slightly calcareous.	3.4
1	Siltstone/claystone; moderate yellow (5 Y 7/6), dark yellowish orange (10 YR 6/6), very light gray (N8), yellowish gray (5 Y 8/1) and very pale orange (10 YR 8/2); thinly bedded to nodular; noncalcareous.	0.3
	Thickness of Moenkopi Formation:	28.1+ m

Section MG-1

SE¼ SE¼ NE¼ sec. 10, T5N, R4W, Mesa Gallina quadrangle, Cibola County, New Mexico; measured 25 June 1987, by S. N. Hayden and B. D. Allen.

unit	lithology	thickness (m)
	Chinle Formation	
	mottled strata:	
16	Mudstone; grayish purple (5 P 4/2), grayish red-purple (5 RP 4/2), very dusky red-purple (5 RP 2/2), dusky red (5 R 3/4) and very dark red (5 R 2/6); 5 to 10 m thick capped by basalt.	not measured
15	Sandstone/conglomerate; grayish red (10 R 4/2), grayish orange-pink (5 R 8/2), pale red (5 R 6/2) and moderate orange-pink (10 R 7/4); stacked channels with graded bedding; clay-pebble layer in some channels.	1.7
14	Sandy siltstone; grayish orange-pink (10 R 8/2), very pale orange (10 YR 8/2), pale yellowish orange (10 YR 8/6), dark yellowish orange (10 YR 6/6), light brown (5 YR 6/4), moderate brown (5 YR 4/4) and pale red-purple (5 RP 6/2); very mottled.	2.0
13	Conglomerate; grayish pink (5 R 8/2), light brownish gray (5 YR 6/1), brownish gray (5 YR 4/1), dark yellowish brown	

(10 YR 4/2), moderate yellowish brown (10 YR 5/4), moderate red (5 R 5/4), moderate reddish brown (10 R 4/6), dusky red (5 R 3/4), grayish red (5 R 4/2) and white (N9); clasts are limestone, chert, siltstone, metamorphic rock fragments and mudstone rip-ups; matrix is coarse to medium grained (250 μm to 1 mm); sand is a lithic wackestone with calcareous cement. 1.2

Disconformity

Moenkopi Formation:

12 Mudstone/siltstone; moderate reddish orange (10 R 6/6) and moderate reddish brown (10 R 4/6) with pale greenish yellow (10 Y 8/2) and moderate orange-pink (5 YR 8/4) mottling; dominantly massive to fissile and calcareous, with a nodular calcrete layer 13 m above the base which is 1.3 m thick. 17.9

11 Siltstone/mudstone; moderate reddish orange (10 R 6/6) and moderate reddish brown (10 R 4/6), with pale greenish yellow (10 Y 8/2) and moderate orange-pink (5 YR 8/4) mottling; thin parallel and ripple laminations; dominantly fissile and calcareous. 6.7

10 Conglomerate/sandstone; pale yellowish brown (10 YR 6/2), grayish brown (5 YR 3/2), moderate brown (5 YR 4/4), grayish red (5 R 4/2 and 10 R 4/2), pale reddish brown (10 R 5/4) and pale red (10 R 6/2); large channel about 1 km wide cuts down through units 8 and 9 into unit 7 where it is 5 to 6 m thick; shows scour surfaces on the order of 1 m or less in thickness; produced fossil bone (capitosauroid amphibian and reptilian), NMMNH locality 360, from approximately 0.4 km to the south, where it has its thickest exposure; clasts are dominantly limestone, siltstone, clay pebbles and chert; graded bedding; matrix-to-clast supported; matrix is lithic wackestone with the same type of clasts plus quartz grains from 2 mm to silt; cement is dominantly calcite intrasparite. 1.5

9 Silty mudstone; same lithology and colors as unit 7. 1.2

8 Sandstone; grayish red (5 R 4/2 and 10 R 4/2), dark reddish brown (10 R 3/4) and grayish orange-pink (5 YR 7/2), weathers to pale reddish brown (10 R 5/4); finely laminated, with some scour marks, low angle trough crossbeds and linguoid ripple marks; sand from 150 μm to silt, consisting of quartz, siltstone, chert and opaques; poorly sorted, very angular to subrounded; cementation is by intrasparite calcite with fine silt in matrix making up 30% of rock. 0.9

7 Siltstone/mudstone with lenses of very calcareous sandstone; silt/clay is moderate orange-pink (10 R 7/4), pale red (5 R 6/2 and 10 R 6/2); sand is light brown (5 YR 6/4), pale yellowish brown (10 YR 6/2), pale yellowish orange (10 YR 7/4) and light olive-gray (5 Y 6/10); sands which have scour bases with rip-up clasts and clay-pebble conglomerate are 0.1 to 0.2 m thick by 1.0 to 1.5 m wide and contain bone fragments; sand is mostly quartz and calcite, and is angular to subrounded, generally less than 350 μm in size; siltstone is rippled in thin laminae, whereas the clay-dominated mudstone is massive; entire unit is very calcareous. 11.7

6 Sandstone (lithic wackestone), light brownish gray (5 YR 6/1), brownish gray (5 YR 4/1), grayish orange-pink (5 YR 7/4), pale brown (5 YR 5/2), moderate orange-pink (10 R 7/4), pale reddish brown (5 R 5/4) and pale red (5 R 6/2); trough crossbedded to ripple laminated to massive with bioturbation and mottling; also contains pebbles up to 1.5 cm in diameter; reactivation surfaces every 0.5 to 1 m with clay-and-silt pebble intraformational conglomerates; sand is quartz, chert, siltstone and limestone lithic fragments with accessory micas and opaques from 500 μm to silt, and is angular to subrounded; forms prominent cliff. 4.9

5 Siltstone; moderate reddish orange (10 R 6/6) and moderate reddish brown (10 R 4/6), with pale greenish yellow (10 Y 8/2) and moderate orange-pink (5 YR 8/4) mottling; thinly laminated to nodular to massive; bioturbated; some starved-ripple silt deposition in muds; dominantly fissile and calcareous; contains small lenticular bodies of very fine, sandy siltstone; forms slope. 9.8

4 Sandstone (lithic wackestone), brownish gray (5 YR 4/1) and grayish red-purple (5 RP 4/2), weathers to dark reddish brown (10 R 3/4) and very dusky red (10 R 2/2); contains channel scours up to 1 m thick with small trough crossbeds, planar beds and some ripple laminae toward the top; sand is from 125 μm to silt, and consists of quartz, siltstone, chert and opaques; poorly sorted; very angular to subrounded; cementation is by intrasparite calcite with fine silt in matrix making up 30% of rock; forms ledge. 2.6

3 Silty mudstone; moderate reddish orange (10 R 6/6), moderate reddish brown (10 R 4/6), dark reddish brown (10 R 3/4) and dusky red (5 R 3/4), with pale greenish yellow (10 Y 8/2) and moderate orange-pink (5 YR 8/4) mottling; massive, bioturbated; some starved-ripple silt deposition in muds; calcareous. 2.0

2 Siltstone/claystone; moderate yellow (5 Y 7/6), dark yellowish orange (10 YR 6/6), very light gray (N8), yellowish gray (5 Y 8/1), very pale orange (10 YR 8/2), grayish orange-pink (10 R 8/2), moderate orange-pink (10 R 7/4) and pale greenish yellow (10 Y 8/2); thinly bedded to nodular; very slightly calcareous to very calcareous; minor very fine sand to 90 μm with liesegang banding, dusky red (5 R 3/4), as channels in the finer-grained units. 8.5

Thickness of Moenkopi Formation: 68.3 m

Disconformity

San Andres Formation:

1 Limestone with goethite on weathered surface; dark yellowish orange (10 YR 6/6), grayish orange (10 YR 7/4), light brown (5 YR 6/4), moderate orange-pink (5 YR 8/4) and dark yellowish brown (10 YR 4/2). not measured

Section SR-1

SE¼ SW¼ SE¼ sec. 4, T9N, R10W, San Rafael quadrangle, Cibola County, New Mexico; measured 23 May 1988, by S. N. Hayden.

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

Chinle Formation

Shinarump Member:

15 Sandstone/conglomerate; yellowish gray (5 Y 8/1) and pinkish gray (5 YR 8/1), weathers brownish gray (5 YR 4/1); trough crossbedded; abundant clast supported conglomerates which grade upward into very coarse sandstones; clasts are mostly limestone and chert pebbles and cobbles up to 12 cm diameter; sands are quartzarenites; cementation is by calcite and silica overgrowths. 9.0+

Chinle Formation

mottled strata:

14 Siltstone/mudstone; grayish purple (5 P 4/2), very dusky red-purple (5 RP 2/2), very pale orange (10 YR 8/2) and white (N9); massive; weathers blocky; mostly covered slope. 4.8

13 Sandstone; grayish red (10 R 4/2), grayish red-purple (5 RP 4/2) and pale yellowish orange (10 YR 8/6); sand is quartz, fine grained to 250 μm and contains rip-up clasts of Moenkopi-like siltstone. 0.2

12 Siltstone; grayish purple (5 P 4/2) and white (N9); massive. 0.7

Disconformity

Moenkopi Formation:

11 Mudstone; same lithology and colors as unit 7, mostly covered. 1.9

10 Sandstone (lithic wackestone), grayish red (10 R 4/2) and pale red (5 R 6/2 and 10 R 6/2), weathers grayish red (5 R 4/2); horizontally bedded to 1.5 cm thick; fine grained to 175 μm. 0.3

9 Mudstone; same lithology and colors as unit 7. 4.5

8 Sandstone/conglomerate; matrix is grayish pink (5 R 8/2), grayish orange-pink (10 R 8/2) and pinkish gray (5 YR 8/1) sandstone; conglomerate is matrix supported with clasts >2.0 cm of black chert, quartzite, limestone and siltstone, and grades into pebbly sandstone which is a lithic wackestone of similar composition; medium grained to 350 μm. 0.3

7 Mudstone/siltstone; grayish red (10 R 4/2), weathers pale reddish brown (10 R 5/4); planar to ripple laminated to thinly bedded; blocky weathering. 1.5

6 Sandstone (lithic arenite), moderate reddish brown (10 R 4/6), grayish red (5 R 4/2) and light brown (5 YR 6/4); trough crossbedded, with two internal bounding surfaces at 0.8 m

	and 1.4 m; sets 0.5 to 2.0 cm thick; medium grained to 500 μm; bioturbated; calcareous cement.	1.9
5	Sandstone (lithic wackestone), light olive-gray (5 Y 6/1) and pale yellowish brown (10 YR 6/2); massive to plane bedded; poorly indurated; calcareous cement.	0.6
4	Sandstone (lithic wackestone), grayish red (10 R 4/2) with white (N9) liesegang banding; planar to trough crossbedded.	0.4
3	Muddy siltstone; moderate reddish brown (10 R 4/6); calcareous.	2.4
2	Silty mudstone to claystone; light olive-gray (5 Y 6/1), pale yellowish brown (10 YR 6/2) and very pale orange (10 YR 8/2); variegated, contains oxidized zones; may be karst fill.	2.5
	Thickness of Moenkopi Formation:	16.3 m
	Disconformity	
	San Andres Formation:	
1	Limestone, light olive-gray (5 Y 6/1); thin to medium bedded; micritic to sandy; has slight apparent angular unconformity with the Moenkopi Formation; may be gently folded.	not measured

Section SR-4

West side of Cerrito Colorado in the SW¼ SE¼ SW¼ sec. 4, T10N, R10W, San Rafael quadrangle, Cibola County, New Mexico; measured 26 May 1988, by S. N. Hayden.

unit	lithology	thickness (m)
	Moenkopi Formation:	
6	Sandstone (lithic arenite), grayish red (10 R 4/2), grayish red-purple (5 RP 4/2) and pale yellowish orange (10 YR 8/6); sand is quartz and lithic rock fragments; medium grained to 500 μm; trough crossbedded to parallel laminated; contains some lenses of coarser bedding.	1.8
5	Conglomerate; clast supported; matrix has same lithology and colors as unit 4; clasts up to 6 cm in diameter, laterally scours up to 0.3 m into unit 4.	0.5
4	Sandstone (pebbly lithic wackestone), brownish gray (5 YR 4/1) and grayish red-purple (5 RP 4/2), weathers to dark reddish brown (10 R 3/4) and very dusky red (10 R 2/2); contains channel scours up to 1 m thick with small trough crossbedding 1–3 cm thick, planar beds and some ripple laminae toward the top; sand from 125 μm to silt, consisting of quartz, siltstone, chert and opaques; poorly sorted; very angular to subrounded; cementation is by intrasparite calcite with fine silt in matrix making up 30% of rock; pebbles mostly are rip-up clasts of Moenkopi siltstone; forms ledge.	2.6
3	Sandstone (lithic wackestone), grayish red (10 R 4/2); planar crossbedded to parallel laminated.	0.4
2	Siltstone/claystone; moderate reddish brown (10 R 4/6); calcareous; rippled to massive; 3-cm-thick pebbly sandstone lens like unit 4, 1.3 m above base.	4.3
1	Sandy siltstone, white (N9), very light gray (N8), moderate yellow (5 Y 7/6), dark yellowish orange (10 YR 6/6), yellowish gray (5 Y 8/1) and very pale orange (10 YR 8/2); not bedded; appears to fill local topography or karst terrain.	1.4
	Thickness of Moenkopi Formation:	11.0+ m

Section BW-1

NE¼ NW¼ SE¼ and the W½ NE¼ sec. 36, T13N, R12W; Prewitt quadrangle, Cibola County, New Mexico; measured 23 June 1988, by S. G. Lucas and T. E. Williamson.

unit	lithology	thickness (m)
	Chinle Formation	
	Petrified Forest Member	
	Sonsela Sandstone Bed:	
23	Sandstone (quartzarenite), pale yellowish orange (10 YR 8/6); lower 3 m has planar crossbedding; this is overlain by conglomeratic base, trough crossbedded sandstone in erosional contact; contains abundant fossilized wood; conglomerate clasts are mostly siliceous-chert and quartzite-pebbles; shows graded bedding toward the top of the section; sand is coarse grained to 1 mm, and the sandstone is supermature.	not measured
	lower part of Petrified Forest Member:	
22	Mudstone; grayish purple (5 P 4/2); very slightly calcareous; upper ⅓ contains nodular calcrete; upper 5.5 m is rubble covered.	21.0
	Bluewater Creek Member (type section):	
21	Silty mudstone; same lithology and colors as unit 15, but with laminar-sandstone interbedding.	9.5
20	Sandstone; grayish red (5 R 4/2), with very pale orange (10 YR 8/2) mottling which may be flaser bedding; lenticular body pinches out laterally; contains lateral accretion deposits; has 0.3 m of laminar sand at base and at least 2 more internal scour surfaces; micaceous; calcareous cementation; very fine grained to 100 μm.	2.4
19	Silty mudstone; dark reddish brown (10 R 3/4) with dark yellowish orange (10 YR 6/6) mottling; contains iron concretions which are dark yellowish orange (10 YR 6/6) and moderate yellowish brown (10 YR 6/4).	5.6
18	Sandstone (sublithic, subarkosic arenite); pale yellowish brown (10 YR 6/2); limestone-pebble conglomerate at base; thinly bedded lenticular sandstone bodies composing wide, sheet-sandstone body, somewhat like unit 12 in fining-upwards packages with mud drapes.	5.8
17	Silty mudstone; same lithology and colors as unit 15.	17.5
16	Sandy siltstone; grayish red (10 R 4/2), weathers to pale reddish brown (5 R 5/4).	0.4
15	Silty mudstone; moderate reddish brown (10 R 4/6); contains thin, greenish-gray sandy layers; calcareous.	6.4
14	Sandstone; same lithology and colors as unit 12 in lower 1.5 m of lenticular sandstone bodies; grades upward into siltstone and silty mudstone; mud is medium gray (N5), medium light gray (N6) and brownish gray (5 YR 4/1); calcareous; in places there are thin (up to 2 mm), platy gypsum layers and nodular, muddy calcrete, both of which are grayish red (10 R 4/2); contains concretions.	4.1
13	Sandstone/conglomerate; intraformational conglomerate containing mudstone-siltstone- and limestone-pebble clasts in a matrix of, and interbedded with, sandstone with same lithology and colors as unit 12; contains calcrete nodules.	0.2
12	Sandstone (quartzarenite), yellowish gray (5 Y 8/1) and pinkish gray (5 YR 8/1), weathers brownish gray (5 YR 4/1) and olive-gray (5 Y 4/1); ripple laminated; calcite cement; fine grained to 250 μm.	0.3–1.0
	mottled strata:	
11	Limestone; same lithology as unit 10, but lighter colored; mostly light olive-gray (5 Y 6/1) and yellowish gray (5 Y 8/1).	1.5
10	Silty, sandy limestone (micrite to sparite), light brownish gray (5 YR 6/1), brownish gray (5 YR 4/1) and medium gray (N5); clastic content is mostly clay and silt with calcite cement.	6.1
	Disconformity	
	Moenkopi Formation:	
9	Sandy siltstone; same lithology and colors as unit 3, but only slightly calcareous.	0.4
8	Sandstone (lithic wackestone); very mottled grayish red (5 R 4/2), very pale orange (10 YR 8/2), light brown (5 YR 6/4), moderate brown (5 YR 4/4), pale yellowish orange (10 YR 8/6) and grayish purple (5 P 4/2); sand is quartz up to 250 μm in size and siltstone, limestone and chert lithic rock fragments up to 1.0 mm; matrix consists of calcareous silt, much of which has been recrystallized to intramicrite and intrasparite cement; matrix makes up approximately 25% of total; sand is immature, contains faint purple rhizoliths.	1.2
7	Sandstone/conglomerate; same lithology and colors as unit 6, but matrix also consists of intraformational rock fragments, i.e., sand-sized clasts of Moenkopi siltstone; clast size is generally smaller and there is more clast-supported conglomerate.	1.5
6	Sandstone/conglomerate (lithic wackestone), grayish pink (5 R 8/2), grayish orange-pink (10 R 8/2) and pinkish gray (5 YR 8/1); sand is quartz and lithic grains of siltstone, chert and limestone with up to 20% calcareous silt and mud making up a calcareous cement; interbedded conglomerates are matrix supported and consist of pebble-sized clasts of siltstone, chert and limestone up to 3 cm in diameter in a matrix of the same lithic-wacke sandstone as above.	0.7

unit	lithology	thickness (m)
5	Sandstone (lithic wackestone), grayish red (10 R 4/2), pale red (5 R 4/2 and 10 R 4/2), weather grayish red (5 R 4/2); matrix is slightly calcareous silt and calcite cement making up 15% to 20% of the rock; sand consists of subequal amounts of quartz and lithic rock fragments of polycrystalline quartz, siltstone, limestone and chert with accessory micas and opaque minerals; trough crossbedded; chert-pebble lag deposit at base; forms prominent cliff.	2.8
4	Sandy siltstone; grayish red (10 R 4/2), weathers to moderate brown (5 YR 3/4); massive siltstone with thin (up to 0.6 m) sandy siltstone in lower half; sand is quartz and lithic rock fragments up to 500 μm; silt is calcareous; cementation by calcite.	6.2
3	Sandstone/conglomerate (lithic wackestone), grayish red (10 R 4/2), very pale green (10 G 8/2), pale green (5 G 7/2) and very dusky purple (5 RP 2/2); sand and conglomerate clasts are lithic rock fragments of limestone and siltstone; cementation is by intramicrite and intrasparite calcite.	0.2
2	Siltstone; grayish red (10 R 4/2), weathers pale reddish brown (10 R 5/4); ripple laminated to massive; weathers blocky; contains some fine to very fine sand up to 250 μm, consisting of quartz, opaque minerals and minor micas; cementation by calcite. NMMNH locality 356 in lower 0.5 m.	1.6
	Thickness of Moenkopi Formation:	14.6 m
Disconformity		
San Andres Formation:		
1	Micritic limestone; pale yellowish brown (10 YR 4/2), light olive-gray (5 Y 6/1) and light brownish gray (5 YR 6/1); with pale brown (5 YR 5/2) allochems, up to 2 cm on long axis; weathers to moderate reddish brown (10 R 4/6).	not measured

Section CC-1

W½ NW¼ SW¼ SW¼ sec. 19, T13N, R13W, Cottonwood Canyon quadrangle, McKinley County, New Mexico; measured 3 January 1989, by S. G. Lucas, S. N. Hayden and A. P. Hunt.

unit	lithology	thickness (m)
Moenkopi Formation:		
11	Sandstone (lithic wackestone), moderate yellowish brown (10 YR 5/4), light brown (5 YR 6/4), moderate reddish brown (10 R 4/6) and brownish black (5 YR 2/1), weathers pale reddish brown (10 R 5/4), pale red (5 R 6/2) and (10 R 6/2); ripple laminated to low-angle trough crossbeds; sand is quartz, chert, siltstone and mafic lithics; abundant hematite and manganese oxide staining; minor calcite cement.	0.5+
Disconformity		
San Andres Formation:		
10	Limestone, micrite; light olive-gray (5 Y 6/1) and medium light gray (N6), weathers to grayish pink (5 R 8/2) in a rind up to 1 mm thick; blocky lower 0.5 m ledge at base overlain by thinly bedded limestone containing some silicified crinoid fragments.	1.5
9	Shale; medium dark gray (N4) and medium gray (N5); minor silt.	1.1
8	Nodular limestone layer in shale like unit 7, nodules are micrite, medium gray (N5), light brownish gray (5 YR 6/1), very light gray (N8) and yellowish gray (5 Y 8/1).	1.0
7	Shale; medium dark gray (N4), greenish blue (5 BP 5/2) and minor dark yellowish orange (10 YR 6/6).	0.6
6	Nodular limestone layer; same lithology and colors as unit 8.	0.1
5	Shale like unit 7, but nodular at base, yielded fragment of amphibian armor from slope wash, NMMNH locality 355; calcareous.	0.7
4	Siltstone; medium gray (N5), light olive-gray (5 Y 6/1) and moderate yellowish brown (10 YR 5/4); fines to clay-dominated mud at top; noncalcareous.	1.0
3	Sandy siltstone; light olive-gray (5 Y 6/1) and light gray (N7), weathers grayish orange (10 YR 7/4); contains carbonized plant debris; sand is quartz to 300 μm; calcareous.	1.0
2	Siltstone/sandstone interbeds; sand is dark yellowish orange (10 YR 6/6), dark yellowish brown (10 YR 4/2), light gray (N7) and yellowish gray (5 Y 8/1); siltstone occurs as light gray (N6) mud drapes; contains very abundant carbonized plant debris and fossil wood; swaley bedding.	0.7
1	Limestone; medium dark gray (N4); creek-bed exposure; top is unevenly weathered to vuggy texture; base of exposure.	not measured

Section FW-2

E½ NW¼ NE¼ and N½ NE¼ SW¼ NE¼ sec. 9 (unsurveyed), T14N, R16W, Fort Wingate quadrangle, McKinley County, New Mexico; measured 9 July 1988, by S. G. Lucas and S. N. Hayden.

unit	lithology	thickness (m)
Chinle Formation		
Bluewater Creek Member:		
9	Mudstone; same lithology and colors as unit 6.	10.5
8	Siltstone (60%) and mudstone (40%) interbeds; same lithologies and colors as units 6 and 7.	2.8
7	Siltstone; pale reddish brown (10 R 5/4); current ripple laminations 2–8 mm thick; calcareous; forms prominent ledge.	1.0
6	Mudstone; moderate reddish brown (10 R 4/6); massive; very calcareous, contains siderite/calcite nodules which are grayish red (5 R 4/2 and 10 R 4/2) and pale reddish brown (10 R 5/4); has thinly ripple laminar, platy (up to 0.3 m thick) siltstone beds which are also very calcareous.	8.1
5	Silty mudstone; grayish red-purple (5 RP 4/2), pale red-purple (5 RP 6/2), pale pink (5 RP 8/2) and grayish orange-pink (10 R 8/2); massive, contains some fine sand, minor calcite.	3.0
4	Mudstone; pale red (5 R 6/2 and 10 R 6/2), grayish pink (5 R 8/2) light brownish gray (5 YR 6/1), pale red-purple (5 RP 6/2) and very pale orange (10 YR 8/2); contains siderite/calcite nodule rich layers; some bleached out lenticular siltstone beds; mostly massive; mud is noncalcareous.	5.5
3	Silty mudstone; light brownish gray (5 YR 6/1); massive; calcareous; with nodular layer which is brownish gray (5 YR 4/1) and light gray (N7); nodules of siderite/calcite up to 10 cm in diameter.	0.7
2	Mudstone; light brownish gray (5 YR 6/1); massive with platy gypsum; noncalcareous to very slightly calcareous, bentonitic.	5.3
mottled strata:		
1	Siltstone; medium dark gray (N4), medium gray (N5) and medium light gray (N6); abundant nodular gypsum weathering out 3 m above base; nodules are moderate reddish brown (10 R 6/6); mottled; very bioturbated.	7.9+

Section FW-1

SW¼ SE¼ NW¼ sec. 9 (unsurveyed), T14N, R16W, Fort Wingate quadrangle, McKinley County, New Mexico; measured 11 June 1988, by S. G. Lucas, T. E. Williamson and P. Sealey.

unit	lithology	thickness (m)
Chinle Formation		
Shinarump Member:		
6	Sandstone/conglomerate (subarkosic, lithic wackestone), moderate orange-pink (5 YR 8/4), dark yellowish brown (10 YR 4/2), light brown (5 YR 6/4), moderate brown (5 YR 4/4), moderate reddish orange (10 R 6/6), dark reddish brown (10 R 3/4) and grayish red (5 R 4/2); planar crossbeds, ripple-laminar and upper plane bed with parting lineations and reactivation surfaces; sand is mostly medium-grained up to 400 μm but poorly sorted with grains up to 700 μm, contains quartz, k-spar, mafic, chert and siltstone lithics; pebbles in conglomerate lags are siltstone, limestone and chert; calcareous cement; contains plant impressions; forms cap on ridge.	2.5+
mottled strata:		
5	Sandstone (lithic wackestone), grayish red-purple (5 RP 4/2) and grayish purple (5 P 4/2), with minor moderate orange-pink (10 R 6/6), grayish brown (5 YR 3/2), medium gray (N5) and pale brown (5 YR 5/2); sand is graded from very fine, under 100 μm in some layers to very coarse, greater than 2 mm in others; it consists of quartz, plus siltstone, chert and mafic lithics; immature; cementation is by calcite, siderite and silica overgrowths.	7.6
4	Mudstone; pale pink (5 RP 8/2), white (N9), brownish black (5 YR 2/1), pale yellowish orange (10 YR 8/6) and moderate	

	orange-pink (10 R 7/4); silty; contains very abundant "rhizolith forest"; NMMNH locality 358.	1.5
3	Pebbly sandstone/siltstone; pale reddish brown (10 R 5/4), dusky red (5 R 3/4), dark reddish brown (10 R 3/4), moderate orange-pink (5 YR 8/4), grayish brown (5 YR 3/2) and dusky brown (5 YR 2/2); sand is immature, mostly smaller than medium-grained (500 μm), but locally pebbly with quartzite, chert and siltstone clasts up to 1.5 cm in diameter; minor calcite cement; forms prominent bench.	0.5
2	Sandstone/siltstone; same lithology and colors as unit 3 but not as pebbly; contains abundant vertical root casts, which may be as much as 20 cm in diameter; contains local pods of chert pebbles.	11.7
	Disconformity	
	Moenkopi Formation:	
1	Interbedded lithic wacke sandstone and sandy siltstones with mud drapes; grayish red (10 R 4/2) and pale reddish brown (10 R 5/4); immature; sand is fine grained (less than 250 μm); some calcareous cement; abundant silt.	not measured

Section UN-1

NW¼ SW¼ sec. 8, T12N, R16W, Upper Nutria quadrangle, McKinley County, New Mexico; measured 17 August 1988, by S. G. Lucas and O. J. Anderson.

unit	lithology	thickness (m)
	Chinle Formation	
	mottled strata:	
5	Sandstone (subarkosic lithic wackestone), grayish orange-pink (10 R 8/2), dark yellowish orange (10 YR 6/6), grayish purple (5 P 4/2), pale pink (5 RP 8/2) and medium gray (N5); sand is quartz, feldspar, mafic minerals, chert and siltstone; immature and up to 350 μm grain size; some calcareous cement.	not measured
	Disconformity	
	Moenkopi Formation:	
4	Sandstone (lithic wackestone), grayish red (10 R 4/2), pale red (5 R 6/2), weathers pale reddish brown (10 R 5/4); sand is quartz, chert, siltstone and limestone clasts; immature; grain size from fine silt to 250 μm; calcareous cement; low-angle trough crossbeds and ripple laminations.	2.1
3	Mudstone; moderate reddish brown (10 R 4/6), pale reddish brown (10 R 5/4); blocky slope former; minor very fine silt; slightly calcareous.	4.4
2	Sandy siltstone; grayish red (10 R 4/2), weathers moderate reddish brown (10 R 4/6); laminar; sand is very fine up to 100 μm, calcareous cement.	0.7
	Thickness of Moenkopi Formation:	7.2 m
	Disconformity	
	San Andres Formation:	
1	Limestone; recrystallized; sparite; light brownish gray (5 YR 8/1), grayish orange-pink (5 YR 7/2), weathers moderate orange-pink (5 YR 8/4), light brown (5 YR 6/4 and 5 YR 5/6) and grayish orange (10 YR 7/4); hummocky bedded; banded; contains crinoid detritus and productoid brachiopods.	2.0+

Section UN-2

NE¼ NW¼ sec. 7, T12N, R16W, Upper Nutria quadrangle, McKinley County, New Mexico; measured 9 July 1988, by S. G. Lucas and S. N. Hayden; bedding dips 72° to 250° azimuth.

unit	lithology	thickness (m)
	Zuni Sandstone (undivided):	
6	Sandstone (quartzarenite), moderate reddish orange (10 R 6/6), grayish pink (5 R 8/2) and moderate orange-pink (10 R 7/4); large-scale trough crossbedding above gradational basal contact; medium grained to 400 μm; mature; calcareous cement.	not measured
	Zuni Sandstone	
	Iyanbito Member:	
5	Sandstone (subarkosic, sublithic arenite), moderate reddish orange (5 YR 6/6) and light brown (5 YR 5/6); trough cross-bedded; contains pebbles up to 2–3 cm in diameter of chert and quartzite; sand is submature; calcite cement.	1.6
4	Sandstone (subarkosic, sublithic arenite), grayish pink (5 Y 8/2) and moderate orange-pink (10 R 7/4); trough cross-bedded, not pebbly; coarse grained to 700 μm; submature; calcite cement.	1.7
3	Conglomeratic sandstone; sand is moderate reddish orange (10 R 6/6) and light brown (5 R 6/4) and is like unit 4; pebbles up to 10 cm of quartzite, chert and quartz grains.	2.0
2	Sandstone; same lithology and colors as unit 4.	1.2
	Disconformity	
	Chinle Formation	
	Rock Point Member:	
1	Sandstone/siltstone interbeds; mostly covered slope, sandstone is moderate reddish orange (10 R 6/6), grayish orange-pink (10 R 8/2), grayish pink (5 R 8/2) and light brown (5 YR 6/4); siltstone is moderate reddish brown (10 R 4/6) and pale reddish brown (10 R 4/1); sand is immature quartz wacke sandstone up to 400 μm grain size; calcite cement; silt is slightly calcareous.	not measured

Section LC-1

SW¼ SE¼ NE¼ sec. 3, T3N, R19W; Catron County, New Mexico; measured 8 July 1988, by S. G. Lucas and S. N. Hayden.

unit	lithology	thickness (m)
	Dakota Formation:	
14	Sandstone (quartzarenite), pale yellowish orange (10 YR 8/6) and grayish orange (10 YR 7/4); trough crossbedded; medium grained (to 400 μm); calcareous cement; forms ledge.	not measured
13	Sandstone/conglomerate; grayish yellow-green (5 GY 7/2), dusky yellow-green (5 GY 5/2), yellowish gray (5 Y 7/2) and dusky yellow (5 Y 6/4); sand is quartz up to 200 μm, chert, siltstone, micas and some mafic lithics of varying grain sizes up to coarse sand; conglomerate is matrix supported, with clasts of quartzite and chert; contains oxidized plant debris.	0.6
	Disconformity	
	Chinle Formation	
	upper part of Petrified Forest Member:	
12	Silty mudstone; pale greenish yellow (10 Y 8/2), pale olive (10 Y 6/2) and grayish yellow-green (5 GY 7/2); "bleach-out" below disconformity.	5.9
11	Silty mudstone; grayish red (10 R 4/2), with pale greenish yellow (10 Y 8/2) mottling; "popcorn" weathering; calcareous.	6.8
10	Sandstone; same lithology and colors as unit 6, but contains higher amount of mud.	7.2
9	Sandstone; same lithology and colors as unit 7.	1.4
8	Sandstone; same lithology and colors as unit 6.	3.0
7	Sandstone (lithic arenite), pale red (5 R 6/2 and 10 R 6/2), with grayish red (5 R 4/2) bases of laminae in parallel laminations interbedded with grayish red (10 R 4/2) siltstone; contains light greenish gray (5 GY 8/1), lenticular sandstone bodies; ripple to parallel laminated; sand is fine grained to 150 μm and consists of quartz, chert, siltstone and mafic lithics.	5.8
6	Sandstone (lithic arenite); same colors as unit 4, finer grained, up to 300 μm; small trough crossbeds; poorly indurated, forms slope; sand is quartz, chert and mafic lithics; contains calcrete nodules with Fe staining; calcareous cement.	1.8
5	Sandstone; same lithology and colors as unit 3.	0.1
4	Sandstone (lithic arenite), light gray (N7) and pale purple (5 PB 7/2), with medium dark gray (N4) markings on base of laminations in trough crossbeds; sand is quartz, pinkish siltstone, chert and mafic lithics; coarse grained to 500 μm; intrasparite calcite cement.	0.7
3	Sandstone (lithic arenite), yellowish gray (5 Y 7/2), weathers to light olive-gray (5 Y 6/1); fine grained to 250 μm; sand is quartz and mafic lithics; contains lateral accretion structures; parallel laminations showing parting lineations; claystone interbeds; contains abundant petrfied wood.	3.2

2	Siltstone; grayish red (5 R 4/2) with grayish pink (5 R 8/2) and grayish orange-pink (5 YR 7/2) mottling; contains lunate ripples and concretions; slightly calcareous in lighter colored areas.	2.9
1	Sandstone (subarkosic, lithic wackestone), pale red (10 R 6/2), grayish pink (5 R 8/2), pale pink (5 RP 8/2) and yellowish gray (5 Y 8/1); siltier in red areas; poorly indurated; friable; slope former; noncalcareous; base not exposed.	not measured

APPENDIX 2—FOSSIL LOCALITIES

Map information for fossil localities mentioned in the text is listed here.

NMMNH locality 355—SW¼ NW¼ SW¼ SW¼ sec. 19, T13N, R14W, McKinley County; Permian San Andres Formation.

NMMNH locality 356—SE¼ NE¼ NW¼ SE¼ sec. 36, T13N, R12W, Cibola County; Early-Middle Triassic Moenkopi Formation.

NMMNH locality 357—NE¼ NW¼ NE¼ NW¼ sec. 16 (unsurveyed), T14N, R16W, McKinley County; Late Triassic Sonsela Sandstone Bed, Petrified Forest Member, Chinle Formation.

NMMNH locality 358—NW¼ NW¼ NE¼ SW¼ sec. 9 (unsurveyed), T14N, R16W, McKinley County; Late Triassic? mottled strata of Chinle Formation.

NMMNH locality 359—NE¼ SW¼ NW¼ SE¼ sec. 10, T5N, R4W, Cibola County; Early-Middle Triassic Moenkopi Formation.

NMMNH locality 360—SW¼ NW¼ NE¼ SE¼ sec. 10, T5N, R4W, Cibola County; Early-Middle Triassic Moenkopi Formation.

Dowa Yalanne (Corn Mountain) looking E. Slabby-bedded, dark-colored strata at base of mesa are Rock Point Member of Chinle Formation (Upper Triassic) overlain by white/tan cliffs of Jurassic Zuni Sandstone capped by thin, dark layer of Cretaceous Dakota Sandstone. Note notch in Zuni Sandstone ("Todilto notch") that represents the bounding surface landward of the Todilto salina during the Middle Jurassic. Photograph taken 25 February 1989 by Paul L. Sealey.