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Spencer G. Lucas and Adrian P. Hunt

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TRIASSIC STRATIGRAPHY AND PALEONTOLOGY, CHAMA BASIN AND ADJACENT AREAS, NORTH-CENTRAL NEW MEXICO

SPENCER G. LUCAS[1] and ADRIAN P. HUNT[1,2]

[1]New Mexico Museum of Natural History, 1801 Mountain Road NW, Albuquerque, New Mexico 87104-1375;
[2]Department of Geology, University of New Mexico, Albuquerque, New Mexico 87131-1116

Abstract—Triassic strata in the Chama Basin and along the flanks of the Nacimiento and Jemez Mountains of Rio Arriba and Sandoval Counties, New Mexico, pertain to the Middle Triassic Moenkopi Formation (Anton Chico Member) and the Upper Triassic Chinle Group (Agua Zarca, Salitral, Poleo, Petrified Forest and Rock Point Formations). The Moenkopi Formation is present only along the flanks of the Nacimiento and Jemez Mountains in Sandoval County. It is as much as 39 m thick and consists mostly of grayish red siltstone, mudstone and immature, trough-crossbedded sandstone. The Agua Zarca Formation is as much as 61 m thick and consists mostly of trough-crossbedded, quartzose sandstone and siliceous conglomerate. Near Coyote in Rio Arriba County, it overlies "mottled strata" developed in the top of the Pennsylvanian-Permian Cutler Formation. The Salitral Formation is as much as 102 m of mostly purplish, smectitic mudstone. The Poleo Formation is up to 41 m thick and is mostly grayish yellow, trough-crossbedded litharenites and subarkoses and minor amounts of both intrabasinal and siliceous conglomerate. Above the Poleo Formation, as much as 200 m of strata, dominated by reddish brown, smectitic mudstones, constitute the Petrified Forest Formation. South of San Miguel Canyon in Sandoval County, the Poleo Formation is not present, and all of the mudstone section above the Agua Zarca Formation is assigned to the Petrified Forest Formation. Locally, near San Ysidro, the Correo Member is present at the top of the Petrified Forest Formation. In the Chama physiographic basin, the Rock Point Formation, as much as 70 m thick and mostly reddish brown and grayish red siltstone and ripple-laminar sandstone, disconformably overlies the Petrified Forest Formation. Three formations of the Chinle Group in north-central New Mexico contain biochronologically important fossils, notably the aetosaur *Longosuchus* (late Carnian) in the Salitral Formation, the aetosaur *Typothorax* and the phytosaur *Pseudopalatus* (early-middle Norian) in the Petrified Forest Formation, and a new genus of phytosaur (late Norian/Rhaetian) in the Rock Point Formation. These fossils and lithostratigraphy allow precise correlation of the Chinle Group strata exposed in north-central New Mexico with other Upper Triassic strata in New Mexico.

INTRODUCTION

Triassic strata are exposed in the Chama physiographic basin and along the flanks of the Nacimiento and Jemez Mountains in Rio Arriba and Sandoval Counties of north-central New Mexico (Fig. 1). These strata are of nonmarine origin and are assigned to the Middle Triassic Moenkopi Formation and the Upper Triassic Chinle Group (Lucas, 1992). In this article, we review the stratigraphy and paleontology of these Triassic strata in order to correlate them with Triassic rocks exposed elsewhere in New Mexico.

PREVIOUS STUDIES

The Triassic strata and their contained fossils in north-central New Mexico have been studied by many workers for almost 120 years. Here, we focus on those studies most important to the lithostratigraphy, paleontology and correlation of the Triassic in this region.

Studies of the Triassic stratigraphy and paleontology of the Chama basin began with the work of Cope (1875), who traversed part of north-central New Mexico making geological observations and collecting fossils. Near Gallina, on the northern side of Cerro Blanco (see below), Cope collected the first Upper Triassic vertebrate fossils discovered in the American West (including the type specimens of the reptile *Typothorax coccinarum*) as well as the type specimens of the bivalve *Unio cristonensis*. Cope (1875, 1877) simply referred to the rocks that contained the fossils as Triassic, making no lithostratigraphic assignment. Years later, a professional fossil collector hired by Cope, David Baldwin, collected additional vertebrate fossils from the Triassic of north-central New Mexico (Cope, 1887a, b, 1889).

In an effort to follow up the discoveries of Cope and Baldwin, E. C. Case, S. W. Williston and F. von Huene explored the Permian and Triassic in north-central New Mexico in 1910 (Case and Williston, 1912). Huene (1911) published a short article in which he described the Permian-Cretaceous section at "Mesa Poleo" (Mesa Montosa of current maps). He coined the name "Poleo-top-sandstone" for the Triassic sandstone that caps the mesa, and thus introduced the first lithostratigraphic name for Triassic rocks in north-central New Mexico.

Renick (1931) referred to the Triassic strata in western Sandoval County as "Chinle(?) Formation." He coined the name Senorito sandstone lentil for a medial sandstone-dominated interval of these strata.

Wood and Northrop (1946) mapped the Triassic and adjacent strata in much of north-central New Mexico and assigned the Triassic rocks to the Chinle Formation. They introduced two new stratigraphic units for strata below Huene's (1911) Poleo, the "Agua Zarca sandstone member" and "Salitral shale tongue" of the Chinle Formation. They referred to the stratigraphic unit named by Huene (1911) as the "Poleo sandstone lentil" of the Chinle.

The nomenclature used by Wood and Northrop (1946) has been formally accepted by the U.S. Geological Survey (Keroher et al., 1966) and followed by subsequent authors of the U.S. Geological Survey, with recognition of two Chinle members above the Poleo: Petrified Forest Member overlain locally by the "siltstone member" (Stewart et al., 1972; O'Sullivan, 1974; Dubiel, 1989) (Fig. 2).

Sedimentological studies of the Triassic strata of north-central New Mexico were undertaken by Kurtz (1978; see also Kurtz and Anderson, 1980) and Dubiel (1989). The discovery of the dinosaur quarry at Ghost Ranch (Colbert, 1947) and the nearby Canjilon phytosaur quarry (Camp, 1930; Hunt and Lucas, 1989; Long et al., 1989) demonstrated the great paleontological potential of the strata first collected by Cope and Baldwin. Recent publications on the paleontology of the Triassic in north-central New Mexico include Ash (1974), Colbert (1989) and Hunt and Lucas (1989, 1991).

STRATIGRAPHY

Strata of the Chinle Group in the Chama basin and adjacent areas are assigned to five formations (in ascending order): Agua Zarca, Salitral, Poleo, Petrified Forest and Rock Point. The Middle Triassic Anton Chico Member of the Moenkopi Formation underlies the Chinle Group in part of Sandoval County.

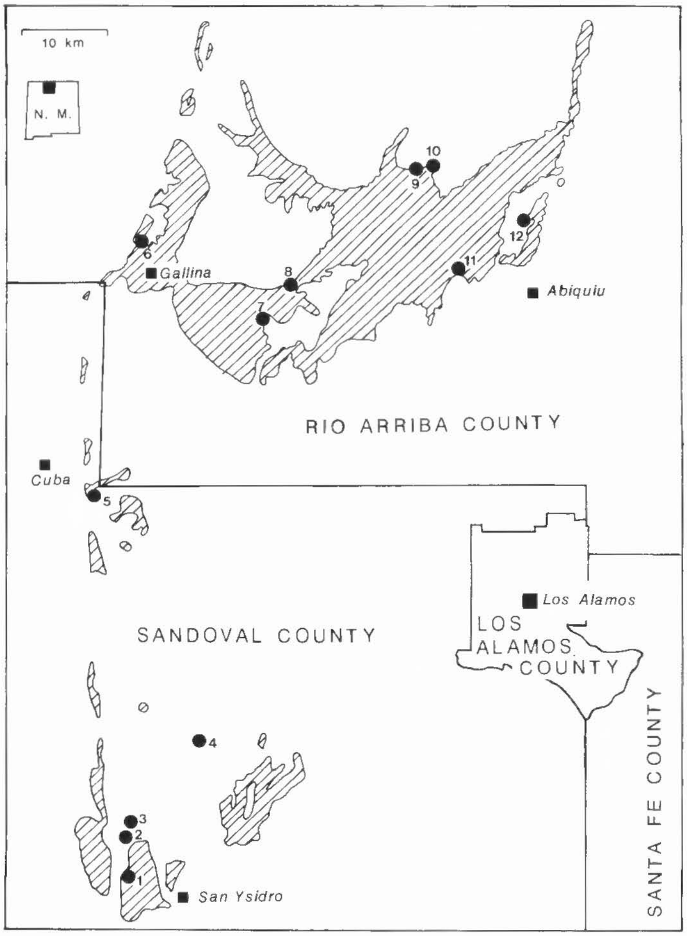


FIGURE 1. Distribution of Triassic strata in the Chama basin and adjacent parts of north-central New Mexico (after Dane and Bachman, 1965). Numbers refer to measured stratigraphic sections in Figs. 3 and 4. 1—Red Mesa, 2—Los Pinos Arroyo (S), 3—Los Pinos Arroyo (N), 4—Guadalupita Mesa, 5—Nacimiento mine, 6—Cerro Blanco, 7—Mesa Montosa, type sections of Agua Zarca and Salitral Formations, type section of Poleo Formation, 8—Coyote amphitheater, 9—Canjilon quarry, 10—*Rioarribasaurus* quarry, 11—Abiquiu Dam, 12—Minas de Pedro.

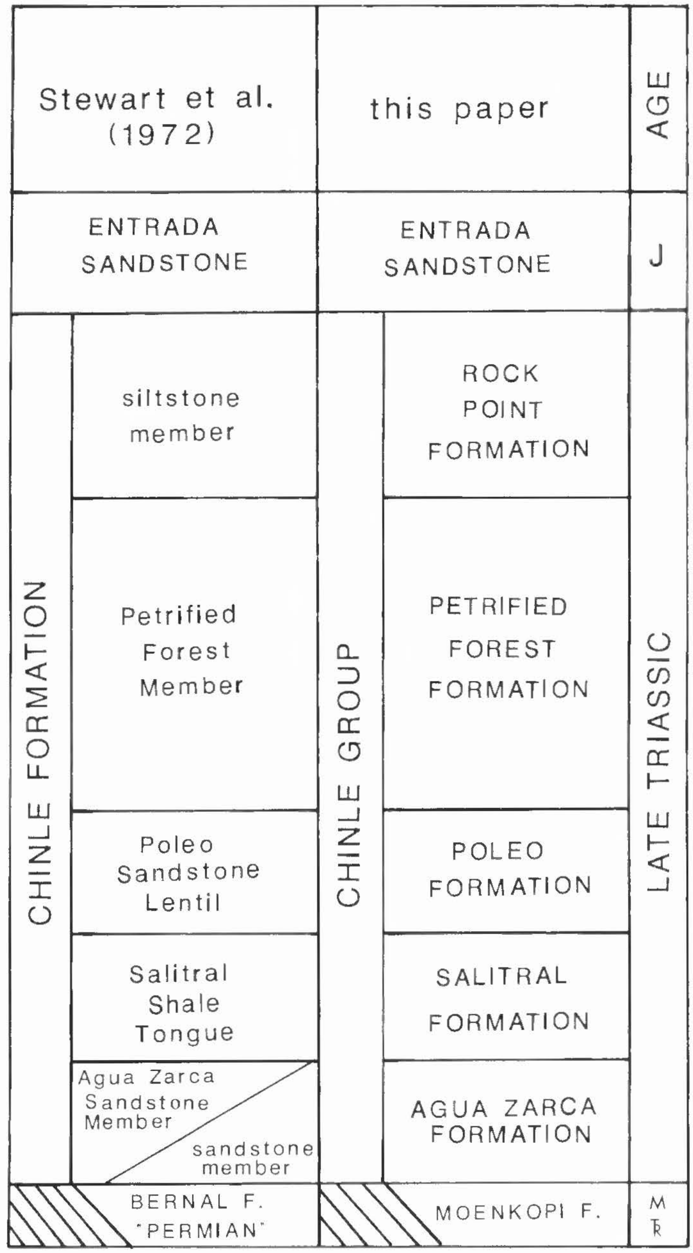


FIGURE 2. Comparison of Triassic stratigraphic nomenclature of Stewart et al. (1972) and the nomenclature advocated in this paper.

Moenkopi Formation

For more than 40 years, the boundary between Permian and Triassic strata in part of north-central New Mexico has been placed between the Permian Bernal Formation and the Chinle Group. This began with Wood and Northrop's (1946) assignment of the youngest Permian strata in the Nacimiento Mountains to the "upper clastic member" of the San Andres Formation. They described this unit as "dark reddish brown sandstone and siltstone," overlain by the Agua Zarca Formation of the Chinle Group. On their map legend, Wood and Northrop (1946) used the acronym "Pb," anticipating Bachman's (1953) introduction of the name Bernal Formation for the unit previously referred to as "the upper clastic member" of the San Andres Formation. Use of the term Bernal Formation for what are supposedly the youngest Permian strata in the Nacimiento Mountains is well entrenched in the literature (e.g., Stewart et al., 1972; Ruetschilling, 1973; Woodward and Martinez, 1974; Woodward and Ruetschilling, 1976; Woodward and Schumacher, 1973; Woodward, 1987).

The type section of the Bernal Formation is at Bernal Butte (sec. 36, T14N, R15E, San Miguel County), about 135 km east of the Nacimiento Mountains (cf. Baltz et al., 1956, p. 42; Lucas and Hayden, 1991). Here, the Bernal Formation is 39 m thick, dominated by massive (intensely bioturbated) reddish brown and reddish orange, very fine-grained sandy siltstone and dolomitic limestone. A 1.5-m-thick gypsum bed is present 10 m above the contact of the Bernal on paleokarst developed in limestone of the San Andres Formation. At its type section, the Bernal Formation is overlain by the Middle Triassic Anton Chico Member of the Moenkopi Formation (Anton Chico Formation of Lucas and Hunt, 1987), a sequence of fluvial strata dominated by grayish red and grayish orange siltstone and immature, trough-crossbedded sandstone (lithic wackes and litharenites) intercalated with some intraformational conglomerate. To the west, south of Lamy in Santa Fe County, these Middle Triassic strata rest on the Bernal Formation (Allen and Lucas, 1988; Lucas, 1991). However, farther west in the Hagan basin and at Placitas, north of Albuquerque, the Middle Triassic Moenkopi Formation rests directly on limestone of the San Andres Formation. No strata lithologically similar to the Bernal Formation are present between the San Andres Formation and Chinle Group west of Lamy. In the Nacimiento Mountains, strata that have been termed Bernal are grayish red and grayish orange siltstones, immature trough-crossbedded sandstones, mudstones and intraformational conglomerates remarkably similar to the Moenkopi strata at Bernal Butte.

Although we have not yet found fossils in the Moenkopi Formation in the Nacimiento Mountains, fossils from lithologically similar strata that occupy the same stratigraphic position to the east and west of the Nacimiento Mountains are of Middle Triassic age. These fossils are capitosauroid amphibians, tetrapod footprints, ostracodes and charophytes that support correlation with the Holbrook Member of the Moenkopi Formation of northeastern Arizona (Lucas and Morales, 1985; Hayden and Lucas, 1988; Kietzke, 1988; Lucas and Hunt, 1991).

We have measured four stratigraphic sections of the Moenkopi Formation in the Nacimiento Mountains (Figs. 3, 5F). In these sections, the Moenkopi has a maximum thickness of 39 m on Guadalupita Mesa. It disconformably overlies grayish orange to very pale orange supermature, trough-crossbedded quartzarenite of the Permian Glorieta Sandstone. A profound erosional disconformity marks the top of the Moenkopi Formation where it is overlain by the Upper Triassic Agua Zarca Formation of the Chinle Group. The basal unit of the Agua Zarca above the disconformity is a siliceous conglomerate that is typically poorly stratified, clast supported and composed of quartite, chert, siltstone and fossil-wood clasts in a pale orange to pale brown matrix of fine- to very coarse-grained quartzose sandstone.

The Moenkopi Formation in the Nacimiento Mountains is dominantly siltstone (52% of the measured sections) with subordinate amounts of mudstone (25%) and sandstone (21%) plus minor conglomerate (2%). The siltstones and mudstones are typically grayish orange to grayish red, sandy and calcareous. Most sandstones are grayish red to pale red, fine- to medium-grained, angular to subrounded wackes. Most Moenkopi conglomerates consist of clay, silt and limestone pebbles in a matrix of sandy siltstone. Sandstones and some siltstones typically display low angle trough-crossbeds (paleocurrent azimuths are to the north or northwest) or laminar bedding. Lateral accretion surfaces, scour-and-fill and medium to coarse grain sizes, among other features, indicate a fluvial environment of deposition for Moenkopi strata in the Nacimiento Mountains.

Chinle Group

Mottled strata

Stewart et al. (1972) used the informal term "mottled strata" for color-mottled strata at the base of the Chinle Group on the Colorado Plateau. These strata are pedogenically modified siltstones, mudstones and sandstones underneath the Shinarump Formation and its equivalents, including the Agua Zarca Formation. The mottled strata represent a paleoweathering profile developed on Permian or pre-Chinle Triassic (Moenkopi) strata. As such, they reflect a pedogenic (erosional) event and are not easily thought of as a stratigraphic unit, although we include the mottled strata in the Chinle Group.

In north-central New Mexico, mottled strata are developed in the top of the Pennsylvanian-Permian Cutler Formation, and are only present at sections where the overlying Agua Zarca Formation is relatively thin (Fig. 4). This reflects the fact that thick Agua Zarca sections represent very large river channels that apparently deeply incised and scoured underlying strata, thus removing the mottled strata (cf. Witkind, 1956).

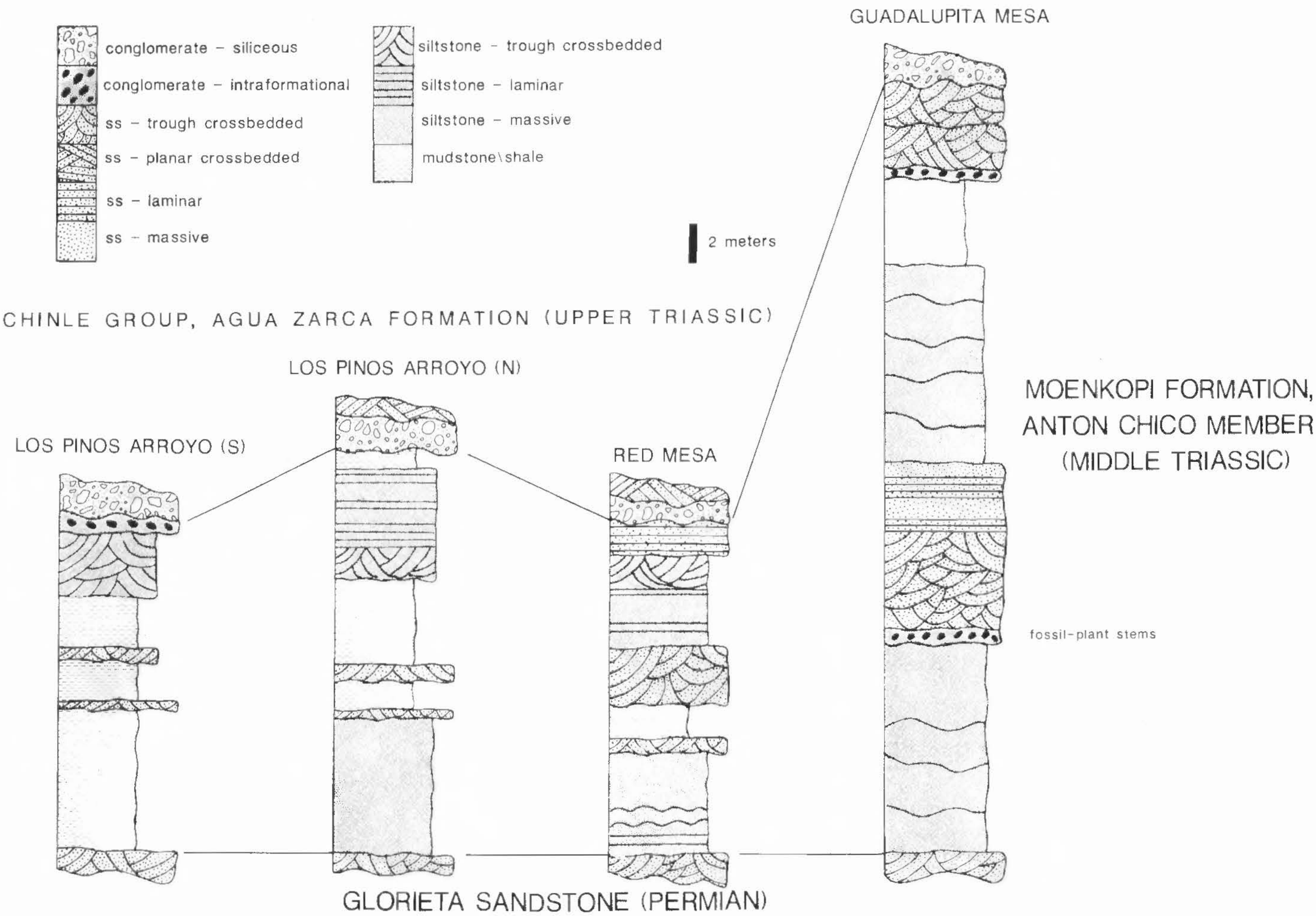


FIGURE 3. Measured stratigraphic sections of the Middle Triassic Moenkopi Formation in the Nacimiento Mountains. Locations of sections are: Los Pinos Arroyo (S)—NW¼ NE¼ NW¼ NW¼ sec. 8 (unsurveyed), T16N, R1E; Los Pinos Arroyo (N)—SE¼ NW¼ SW¼ SW¼ sec. 5 (unsurveyed), T16N, R1E; Red Mesa—SW¼ NE¼ NW¼ SE¼ sec. 32 (unsurveyed), T16N, R1E; Guadalupita Mesa—SW flank of Guadalupita Mesa, 760 m NE of Guadalupe Box (UTM = 3,955,800 N; 350,200 E zone 13).

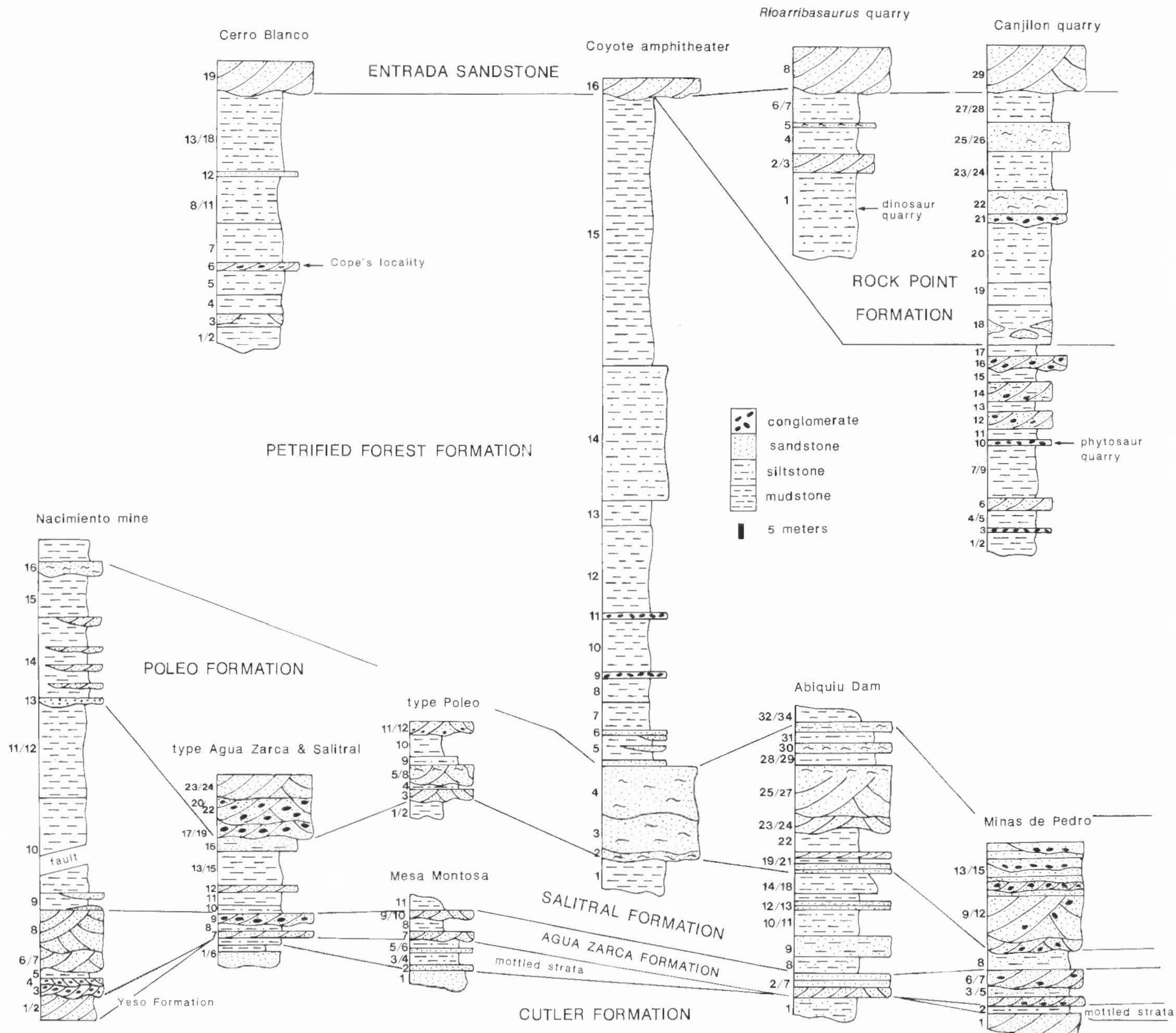


FIGURE 4. Measured stratigraphic sections of Upper Triassic Chinle Group in north-central New Mexico. See Appendix for descriptions of numbered lithologic units.

A typical section of the mottled strata in north-central New Mexico is at Mesa Montosa (Figs. 4, 6A–C). Here, the mottled strata are 7.1 m thick and consist mostly of sandy mudstone, siltstone and sandstone that are color mottled various shades of purple, orange, gray, yellow, green and brown. These strata grade downward into non-mottled Cutler Formation sandstones. It thus is clear that the mottled strata are modified sediments genetically related to the Cutler Formation, but for stratigraphic purposes are most readily mapped with and therefore included in the Chinle Group (Stewart et al., 1972).

Agua Zarca Formation

Wood and Northrop (1946) coined the term "Agua Zarca sandstone member" of the Chinle Formation for the basal Upper Triassic strata in north-central New Mexico. No type section of this unit was designated or described ("the northwest corner of T22N, R3E, west of the village of Coyote" is the only location specifically referred to), but Wood and Northrop (1946) offered the following observations:

> The Agua Zarca sandstone member crops out prominently in the southern and central parts of the area. From the latitude of San Miguel Canyon north it thins rapidly. In Mesa Poleo [Mesa Montosa of current maps] it is thin but still recognizable. This member consists of conglomeratic sandstone with occasional beds of siltstone and silty shale.

Subsequent workers (e.g., Stewart et al., 1972; O'Sullivan, 1974; Dubiel, 1989) have continued to use the term Agua Zarca Sandstone Member, and it has been accepted as a formal stratigraphic name by the U.S. Geological Survey (Keroher et al., 1966). Here, we properly define this stratigraphic unit as the Agua Zarca Formation of the Chinle Group.

The type section (lectostratotype or principal reference section) we designate for the Agua Zarca Formation is just north of Agua Zarca (Sarca) Creek along Salitral Creek, less than 1.6 km northwest of the northwest corner of T22N, R3E (Figs. 1, 4, 5D–E, 6A–C). This section represents well Wood and Northrop's (1946) original concept of the Agua Zarca.

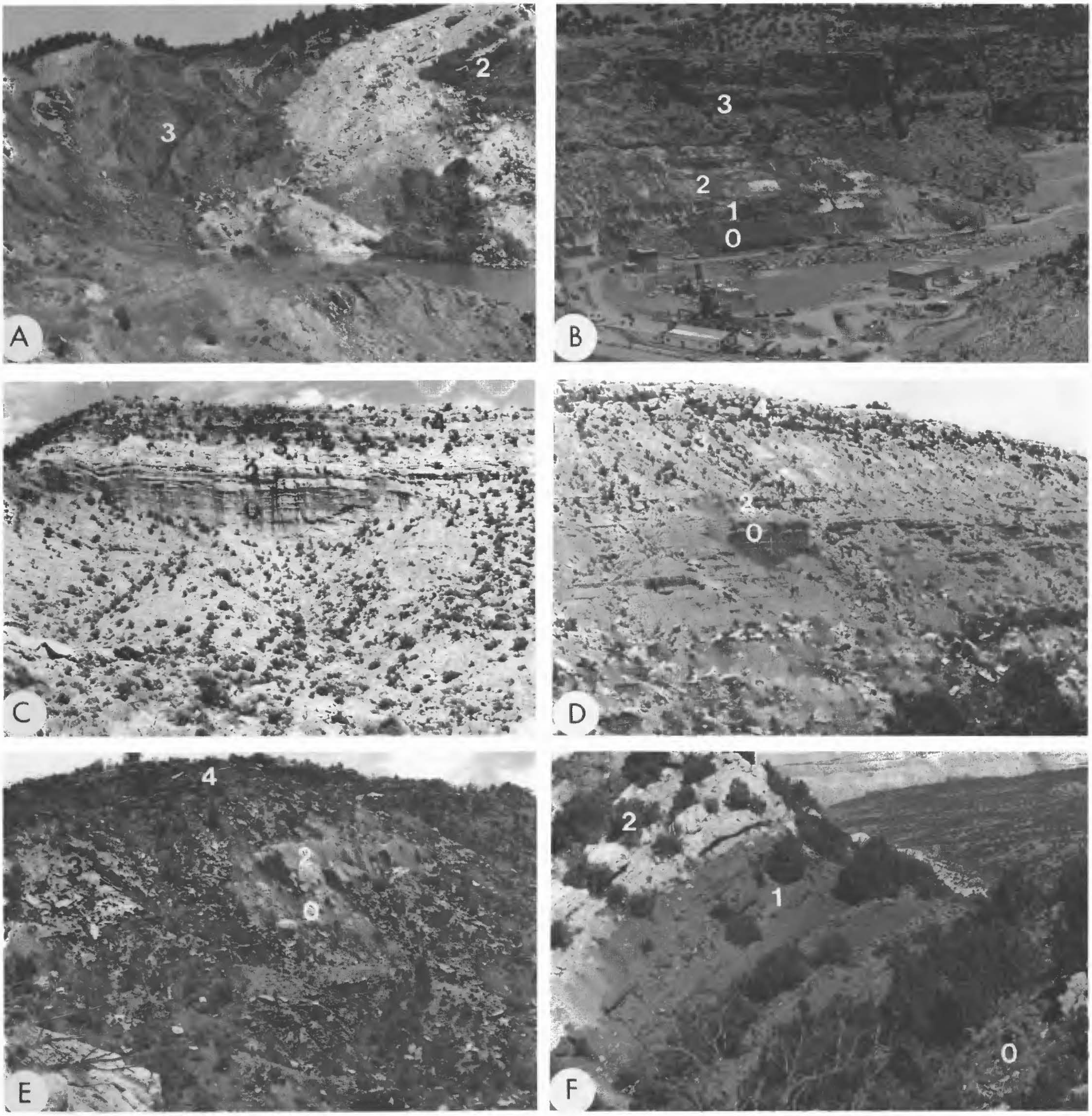


FIGURE 5. Selected outcrops of Triassic strata in north-central New Mexico. A, Faulted outcrops of the Agua Zarca (2) and Salitral (3) Formations at the Nacimiento Mountain copper mine, NW¼ sec. 1, T20N, R1W. B, The Pennsylvanian-Permian Cutler Formation (0) and Upper Triassic Agua Zarca (1), Salitral (2) and Poleo (3) Formations below Abiquiu Dam, N½ sec. 8, T23N, R4E. C, The Pennsylvanian-Permian Cutler Formation (0) and Upper Triassic Agua Zarca (2), Salitral (3) and Poleo (4) Formations at Minas de Pedro, SW¼ sec. 18 (unsurveyed), T24N, R6E. D, The Pennsylvanian-Permian Cutler Formation (0) and Upper Triassic Agua Zarca (2), Salitral (3) and Poleo (4) Formations at Mesa Montosa, sec. 31, T23N, R3E. E, The Pennsylvanian-Permian Cutler Formation (0) and Upper Triassic Agua Zarca (2), Salitral (3) and Poleo (4) Formations along Salitral Creek, SE¼ sec. 36, T23N, R2E. F, The Permian Glorieta Sandstone (0), Middle Triassic Moenkopi Formation (1) and Upper Triassic Agua Zarca Formation (2) at the Los Pinos Arroyo (N) section, sec. 5, T16N, R1E.

At its type section, the Agua Zarca Formation is 5.9 m thick and consists mostly of conglomerate and conglomeratic sandstone (71% of the measured section) with lesser amounts of nonconglomeratic sandstone (18%) and siltstone (11%). Trough crossbedding is the dominant bedform, and sandstone petrology is very mature (quartzose). Colors are mostly greenish gray and grayish yellow. A prominent cliff (ledge) is formed by the Agua Zarca Formation at its type locality above mottled strata developed in the top of the underlying Permian Cutler Formation and below overlying grayish-purple mudstone of the Salitral Formation.

At its type section, and throughout T22N, R3E, the Agua Zarca Formation is relatively thin. Much thicker sections (up to 61 m thick) are present to the south, especially in the La Ventana–San Ysidro area of Sandoval County (Woodward, 1987). Throughout its outcrop area, the Agua Zarca Formation forms a nearly continuous, light-colored ledge of characteristically quartzose sandstone and silica-pebble conglomerate.

In the San Ysidro area, Stewart et al. (1972) referred to the basal sandstone/conglomerate interval of the Chinle Group as the "sandstone

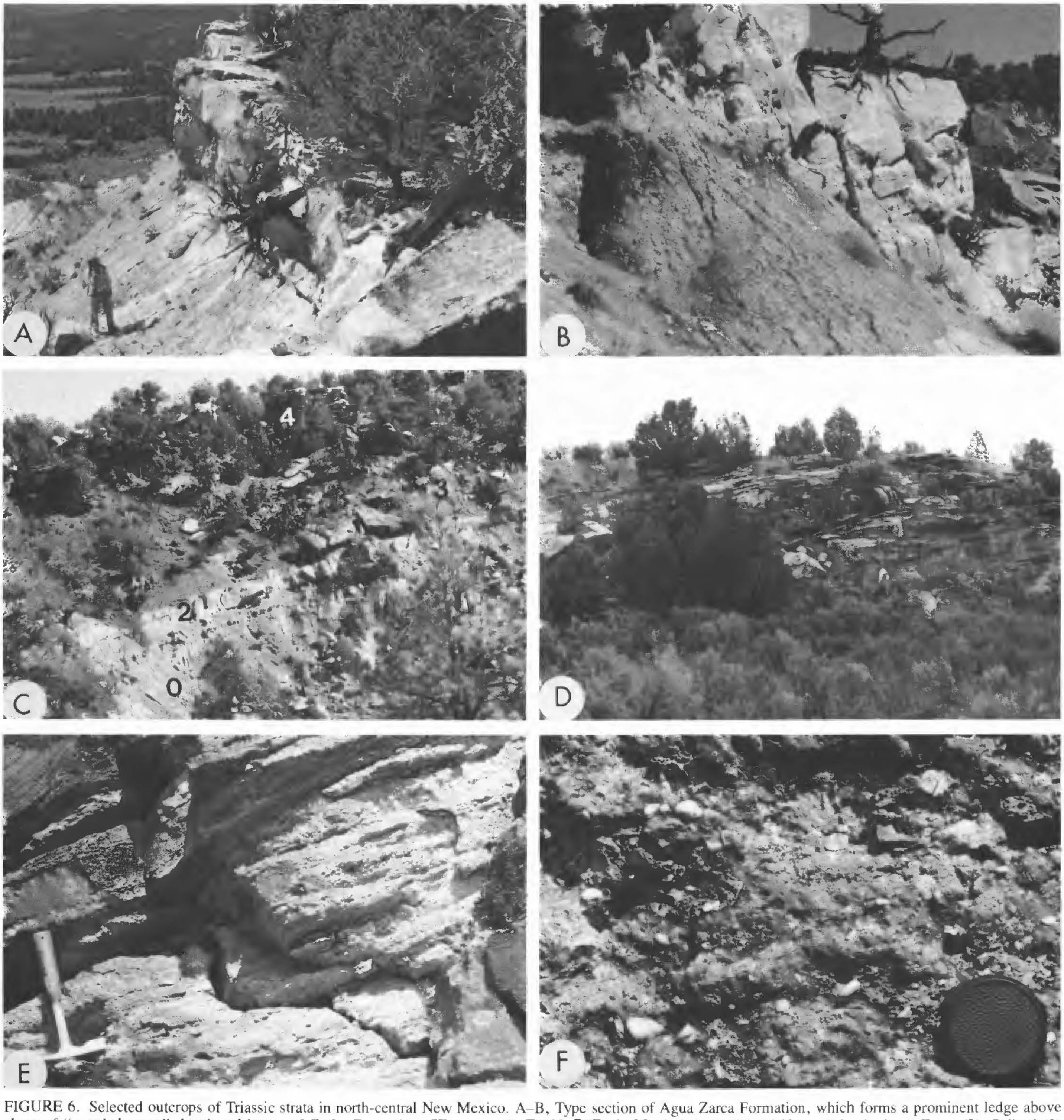


FIGURE 6. Selected outcrops of Triassic strata in north-central New Mexico. A–B, Type section of Agua Zarca Formation, which forms a prominent ledge above slope of "mottled strata" developed in top of Cutler Formation, SE¼ sec. 36, T23N, R2E. C, Mottled strata (0) and Upper Triassic Agua Zarca (2), Salitral (3) and Poleo (4) Formations at type section of Salitral Formation, SE¼ sec. 36, T23N, R2E. D, Type section of Poleo Formation, NW¼ sec. 36, T23N, R2E. E–F, Poleo Formation intrabasinal (E) and extrabasinal (F) conglomerates near the type section of the formation.

member" of the Chinle Formation, not the Agua Zarca Member. They did so because of supposed lithologic differences and the different crossbed dip directions of the Agua Zarca and "sandstone member." Kurtz (1978), in an unpublished master's thesis, subsequently proposed the name "Red Mesa Sandstone" for the "sandstone member" of Stewart et al. (1972). However, the name Red Mesa has already been published by Hoover (1950) for Middle Jurassic strata (= Summerville Formation) at Red Mesa near Kayenta, Arizona.

Woodward (1987), nevertheless, followed Wood and Northrop (1946), in not using the term "sandstone member" and instead applied the name Agua Zarca to the basal Chinle Group sandstone/conglomerate interval in the San Ysidro area. We amplify Woodward's arguments to support this usage as follows:

1. Stewart et al. (1972, p. 23) stated that along Agua Zarca Creek the Agua Zarca "is composed predominantly of red, purple, gray, yellow, and white coarse to very coarse grained sandstone containing conglomerate lenses with pebbles and cobbles as much as 3 inches in diameter." They went on to state that the "sandstone member, on the other hand, is predominantly very pale orange and yellowish-gray fine- to medium-grained sandstone containing conglomerate lenses with pebbles rarely exceeding 1 inch in diameter."

Our observations do not bear out this supposed lithologic distinction (Appendix), nor do those of Kurtz (1978). Instead, they indicate overall lithologic similarity of the Agua Zarca Formation at its type locality and the "sandstone member" near San Ysidro, in sandstone mineralogy (quartzose), grain size, siliceous conglomerate-clast composition and clast size and bedforms. Thus, there is no lithologic difference between the Agua Zarca and the "sandstone member."

2. As Ruetschilling (1973), Kurtz (1978) and Kurtz and Anderson (1980) demonstrated, crossbedding within the "sandstone member" is bimodal, not northerly, as indicated by Stewart et al. (1972). There is thus considerable overlap in the crossbed-dip directions of the "type" Agua Zarca and the "sandstone member."

3. The "sandstone member" is overlain by mudstone-dominated strata near San Ysidro that produce late Carnian vertebrate fossils (Hunt and Lucas, 1990a). Thus, the "sandstone member" is older than the Poleo Formation and cannot be, even in part, its lateral equivalent, as suggested by Kurtz (1978).

4. Finally, as Woodward (1987) pointed out, the only section of the "sandstone member" Stewart et al. (1972, fig. 8, p. 209–210) described, is fault repeated, thus structurally thickening the unit.

Salitral Formation

Wood and Northrop (1946) introduced the name "Salitral shale tongue" of the Chinle Formation for "variegated shale with limestone concretions" that is "above the Agua Zarca sandstone member and below the Poleo sandstone lentil." No type section of the Salitral was designated or described, although it is presumably near the northwest corner of T22N, R3E along Salitral Creek. The name Salitral Shale tongue has been used by subsequent workers (Kerohcr et al., 1956; Stewart et al., 1972; Dubiel, 1989), even though this unit is not shale (it is mudstone, siltstone and sandstone), not a tongue (it is the mudstone-dominated stratigraphic interval between the Poleo and Agua Zarca Formations) and it has never been defined properly.

Here, we properly define the Salitral *Formation* of the Chinle Group from its type section (lectostratotype or principal reference section) on Salitral Creek (Figs. 1, 4, 5E, 6C). At its type section, the Salitral Formation is 22.3 m thick and consists mostly of mudstone (74% of the measured section) with much less sandstone (22%) and siltstone (4%). The mudstones are highly smectitic and are typically grayish purple and grayish red. The sandstone is greenish gray, quartzose and trough crossbedded, very much like underlying sandstone of the Agua Zarca Formation. Salitral siltstones are color mottled and represent paleosols. At its type section, the Salitral Formation conformably overlies the Agua Zarca Formation and is disconformably overlain by the Poleo Formation. Vertebrate fossils from the type section indicate that the Salitral Formation is of late Carnian age (see below).

The Salitral Formation is as much as 102 m thick near San Pablo, south of Cuba in Sandoval County (Woodward, 1987). Throughout its outcrop belt it is characterized by purple and blue, powdery mudstone slopes that frequently are littered with light-colored calcrete nodules. South of San Miguel Canyon (T19N, R1W) in Sandoval County, the Poleo Formation is absent, and the Petrified Forest Formation rests directly on the Salitral Formation (Stewart et al., 1972; Kurtz, 1978; Woodward, 1987). As far south as San Ysidro, and indeed as far east as the Hagan basin northeast of Albuquerque (T12N, R5E), the lower part of the thick, mudstone-dominated section above the Agua Zarca Formation has a high percentage of purple and blue variegated beds, like those of the Salitral Formation to the north. Fossil vertebrates from these lower beds also are age equivalent to the Salitral Formation to the north (Hunt and Lucas, 1990a; Lucas, 1991). However, since a mappable contact between lower, Salitral-equivalent mudstones and overlying Petrified Forest Formation mudstones cannot be identified south of San Miguel Canyon (cf. Woodward, 1987), we follow earlier workers by referring to the entire mudstone-dominated Chinle Group section above the Agua Zarca Formation south of San Miguel Canyon as Petrified Forest Formation.

Poleo Formation

Huene (1911) introduced the name "Poleo-top-sandstone" to refer to a 12- to 15-m-thick sandstone that caps "Mesa Poleo" (Mesa Montosa of current maps). Huene (1911, p. 732) described this unit as "Weicher, dickbankiger, graugelber sandstein, den Kamm der Mesa Poleo bildend" ("smooth, thickbedded, grayish yellow sandstone, that forms the crest of Mesa Poleo"). In Huene's (1911, pl. 32) section at "Mesa Poleo" (Fig. 7), he identified a thick sandstone (his unit 9) and underlying conglomerate (his unit 9a) as the "Poleo-top-sandstone." This corresponds to subsequent use of the term "Poleo sandstone lentil" by Wood and Northrop (1946), although Renick (1931) earlier used the term "Senorito sandstone lentil of the Chinle(?)" for this unit. Renick's (1931) term has been abandoned, and Poleo sandstone lentil has been used by all workers subsequent to Wood and Northrop (e.g., Stewart et al., 1972; O'Sullivan, 1974; Kurtz, 1978; Woodward, 1987; Dubiel, 1989). We refer to this unit as the Poleo Formation of the Chinle Group and describe a type section (lectostratotype or principal reference section) just west of Mesa Montosa.

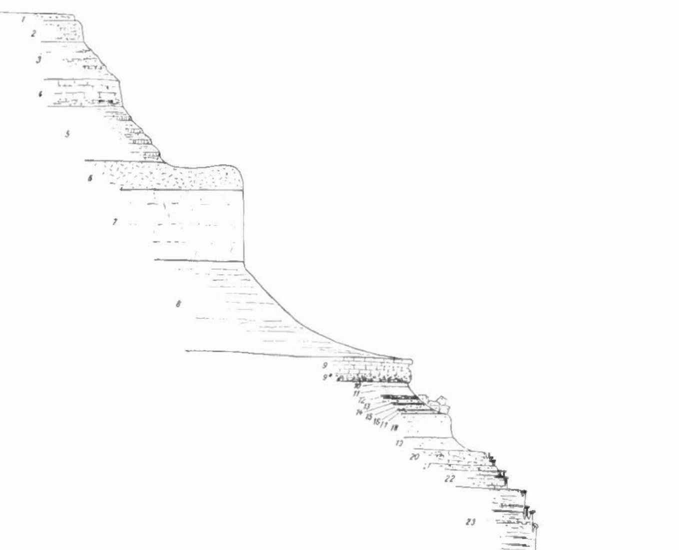


FIGURE 7. Huene's (1911, pl. 22) profile of "Mesa Poleo" (Mesa Montosa) near Coyote. His units are: 1 = Dakota Sandstone (Upper Cretaceous); 2–4 = Morrison Formation (Upper Jurassic–Lower Cretaceous); 5 = Summerville Formation (Middle Jurassic); 6 = Todilto Formation (Middle Jurassic); 7 = Entrada Sandstone (Middle Jurassic); 8 = Petrified Forest Formation, Chinle Group; 9, 9a = Poleo Formation, Chinle Group; 10–17 = Salitral Formation, Chinle Group; 18 = Agua Zarca Formation, Chinle Group; 19–34 = Cutler Formation (Upper Pennsylvanian–Lower Permian).

At its type section (Figs. 1, 4, 5D–E, 6D–F), the Poleo Formation is 10.3 m thick and is almost totally sandstone (94% of measured section). Pebble and conglomeratic beds are mostly intrabasinal; clasts are mudstone/siltstone rip-ups and carbonized/oxidized plant debris. Trough crossbedding is the dominant bedform, and dusky yellow and grayish yellow are the dominant colors. Sandstone petrology is much less mature than Agua Zarca Formation sandstones, with Poleo sandstones being mostly micaceous litharenites and subarkoses. At its type section, the Poleo Formation disconformably overlies the Salitral Formation and is conformably overlain by the Petrified Forest Formation.

The Poleo Formation is exposed throughout the Chama physiographic basin and along the flank of the Nacimiento Mountains as far south as San Miguel Canyon (T19N, R1W, Sandoval County). Its maximum thickness is 41 m, and the Poleo typically defends cuestas and mesa tops throughout its outcrop belt (Figs. 5B–E, 6D). It underlies the extensive dip slope along the northern flank of the Nacimiento Mountains around Gallina in Rio Arriba County (Woodward, 1987; Crouse et al., 1992). Poleo sandstones are always micaceous, many are litharenites and they are typically grayish yellow in color. Conglomerates frequently are intrabasinal, composed of siltstone and nodular calcrete clasts, but some conglomerates of the Poleo Formation are dominated by chert and lesser numbers of quartzite clasts (Fig. 6F).

Reference to the Poleo Formation as a "sandstone lentil" (Wood and Northrop, 1946) is difficult to understand. The Poleo includes conglomerate and siltstone, and we estimate its outcrop area at about 7100 km^2. It is correlative to medial Chinle Group sandstone/conglomerate complexes termed Sonsela Member of the Petrified Forest Formation in west-central New Mexico and Moss Back Formation in southeastern Utah (Lucas, 1992). Subsurface analysis may demonstrate the physical continuity of two, or all three of these units.

Petrified Forest Formation

The thickest unit of the Chinle Group in north-central New Mexico has previously been termed the upper shale member (Wood and Northrop, 1946) or Petrified Forest Member of the Chinle Formation (e.g., Stewart et al., 1972; Dubiel, 1989) and here is termed the Petrified Forest Formation of the Chinle Group (Fig. 4). In north-central New Mexico, the Petrified Forest Formation is as much as 200 m thick where it conformably overlies the Poleo Formation. South of the pinchout of the Poleo Formation, the Petrified Forest Formation, which here includes strata equivalent to the Salitral Formation, is as much as 326 m thick (Ruetschilling, 1973; Woodward, 1987). In the area north of San Ysidro in Sandoval County, a relatively thin (±5 m) sandstone and conglomerate interval at the top of the Petrified Forest Formation is the Correo Member (Lucas et al., 1987, 1988; Lucas, 1991). The Petrified Forest Formation in north-central New Mexico is disconformably overlain by either the Rock Point Formation or the Middle Jurassic Entrada Sandstone. The dominant lithology of the Petrified Forest Formation is reddish brown smectitic mudstone and it forms extensive slopes and dissected badland areas where exposed (Figs. 8A–C, 10).

Rock Point Formation

Stewart et al. (1972) used the term "siltstone member of the Chinle Formation" to refer to the uppermost strata of the Upper Triassic in the Ghost Ranch area. They noted:

> It conformably overlies the Petrified Forest Member of the Chinle Formation and is unconformably overlain by the Entrada Sandstone. It grades into the upper part of the Petrified Forest Member in outcrops to the southwest, but at Ghost Ranch it seems sufficiently well defined to be considered a separate member.

Stewart et al. (1972, p. 40) included the "siltstone member" in their discussion of the "Church Rock Member and Related Units" but were uncertain of its exact correlation. Dubiel (1989, p. B15) subsequently argued that the siltstone member is a correlative of the Owl Rock Member, since "the siltstone member would represent strata deposited on the margins of a large lacustrine basin as represented by the Owl Rock Member. . . ." We, however, take issue with this correlation and some of the conclusions of Stewart et al. (1972). Thus, we identify the "siltstone member" as the Rock Point Formation of the Chinle Group and argue that it disconformably overlies the Petrified Forest Formation. The following points are important:

1. Strata we identify as Rock Point lithologically resemble the Rock Point Formation in the Four Corners area in being alternating beds of fine, laminar/ripple sandstone and non-smectitic siltstone (Fig. 4; Appendix); this is particularly evident on fresh exposures (Fig. 8F). There is no close resemblance to Owl Rock Formation strata, and this is why Dubiel (1989) found it necessary to argue that the "siltstone member" represents a facies (marginal lacustrine) different from the typical Owl Rock facies (lacustrine). It is more parsimonious to argue that the "siltstone member," which lithologically resembles the Rock Point Formation, is the Rock Point Formation in north-central New Mexico.

2. The vertebrate fauna of the Rock Point Formation at Ghost Ranch is younger than the vertebrate fauna of the Petrified Forest and Owl Rock Formations (Lucas, 1992). Indeed, the Owl Rock vertebrate fauna (Kirby, 1989, 1991) is indistinguishable biochronologically from that of the underlying Petrified Forest Formation. In contrast, the Ghost Ranch fauna, principally from the *Rioarribasaurus* quarry, is dominated by dinosaurs and contains the derived phytosaur characteristic of the youngest strata of the Chinle Group (Hunt, 1990), the Rock Point sequence of Lucas (1991, 1992). The "siltstone member" thus postdates the Owl Rock Formation and is the same age as the Rock Point Formation farther west.

3. We know of no evidence that the "siltstone member" interfingers with or grades into the underlying Petrified Forest Formation. Instead, at those sections where the Entrada Sandstone rests directly on the Petrified Forest Formation (Fig. 4), the "siltstone member" has been removed by post-Triassic, pre-Entrada erosion (J-0/J-2 unconformities of Pipiringos and O'Sullivan, 1978). As far as we know, the "siltstone member" is preserved beneath this unconformity only from Echo Amphitheater to Canones Creek (T22N–T25N, R4E, Rio Arriba County). Dubiel (1989, figs. 3, 10) was incorrect in identifying it at Coyote amphitheater and San Miguel Canyon. In both locations the Entrada Sandstone rests directly on the Petrified Forest Formation (Fig. 4; Woodward, 1987).

4. The fact that fossils indicate that the "siltstone member" is correlative with the Rock Point Formation means that no Owl Rock Formation strata are present in north-central New Mexico. This is strong evidence that the Rock Point Formation disconformably overlies the Petrified Forest Formation here, as is the marked lithologic break between the two units.

The Rock Point Formation in north-central New Mexico is as much as 70 m thick. It consists mostly of reddish brown and grayish red massive siltstone and tabular beds of laminar fine sandstone (Figs. 4, 8C–F). It forms either a slope (deeply weathered) or ledgy cliff (relatively unweathered) above the Petrified Forest Formation and below the cliff-forming Entrada Sandstone. Despite former claims that the *Rioarribasaurus* quarry at Ghost Ranch is in the Petrified Forest Formation (e.g., Colbert, 1989), it clearly is in the "siltstone member" of Stewart et al. (1972), i.e., the Rock Point Formation (Hunt and Lucas, 1989, 1991; Figs. 4, 8D–E).

PALEONTOLOGY OF CHINLE GROUP

Introduction

The Chinle Group of north-central New Mexico has yielded many fossils of plants, invertebrates and vertebrates, and the vertebrate specimens in particular are of biochronological importance. The Canjilon quarry (Petrified Forest Formation) near Ghost Ranch, which was discovered by Charles Camp of the University of California in 1928 (Long et al., 1989; Hunt and Lucas, 1989), has yielded the largest single sample of phytosaur skulls and postcrania. Similarly, the *Rioarribasaurus* quarry (Rock Point Formation) at Ghost Ranch, discovered in 1947 by George Whitaker of the American Museum of Natural History (Hunt and Lucas, 1989), has yielded by far the largest single sample of Late Triassic theropod dinosaurs. In addition, there is a very long history of study of Triassic fossils from north-central New Mexico, dating back to the work of E. D. Cope and J. S. Newberry. In 1859, Newberry (1876) collected fossil plants from copper mines in the Agua

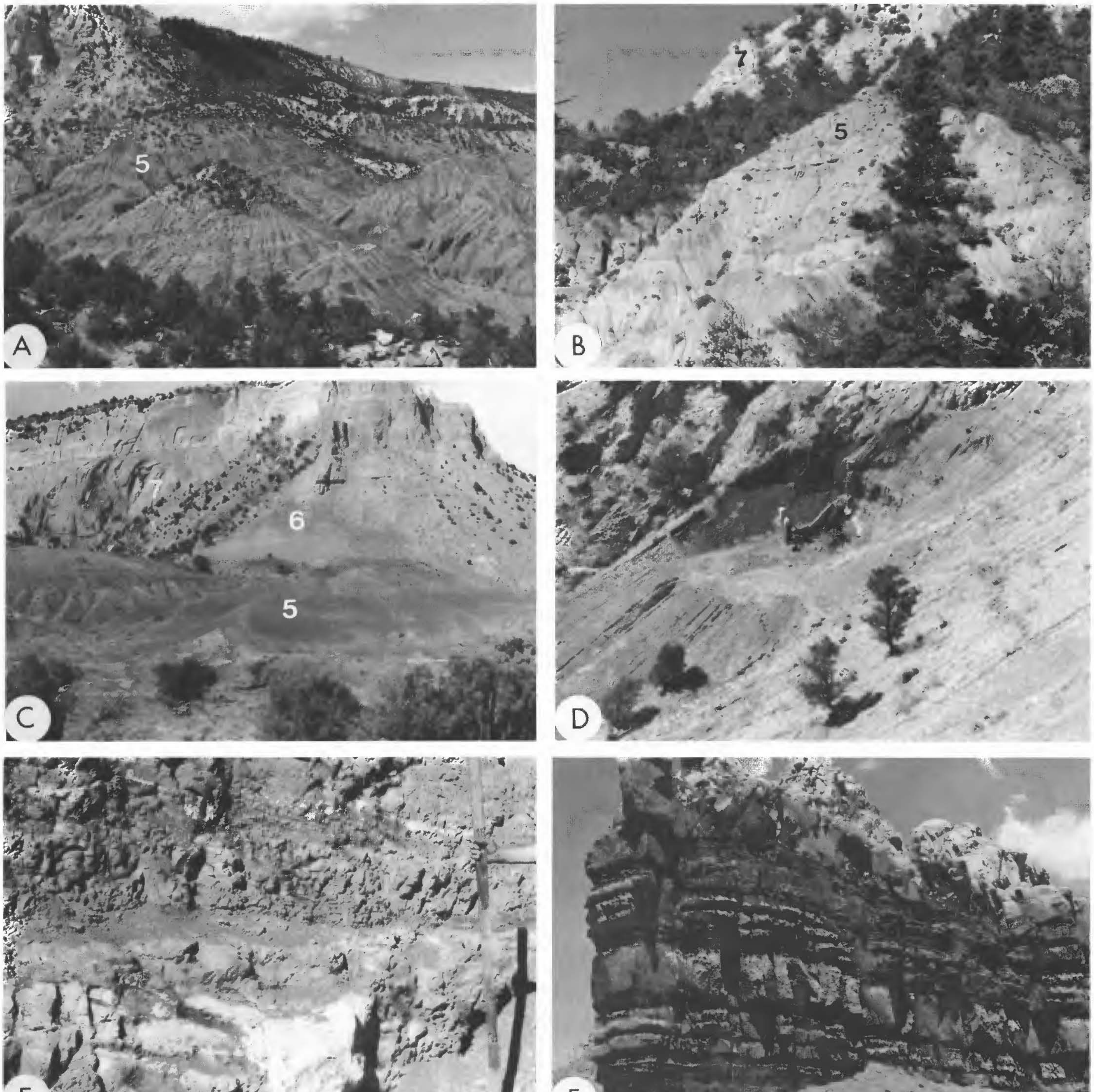


FIGURE 8. Selected outcrops of Triassic strata in north-central New Mexico. A, Petrified Forest Formation (5) overlain by Middle Jurassic Entrada Sandstone (7) at Coyote amphitheater section, NW¼ sec. 21, T23N, R3E. B, Petrified Forest Formation (5) and overlying Entrada Sandstone (7) at Cerro Blanco, NE¼ sec. 4, T23N, R1E. C, Petrified Forest (5), Rock Point (6) and Entrada (7) Formations near the Canjilon phytosaur quarry, SW¼ sec. 2, T24N, R4E. D–E, *Rioarribasaurus* quarry in the Rock Point Formation, SW¼ SE¼ sec. 1, T24N, R4E. F, Fresh exposure of Rock Point Formation, SW¼ sec. 18, T24N, R5E.

Zarca Formation. Subsequently, Cope (1875) identified the first Late Triassic vertebrate fossils in the American West and named *Typothorax*, one of the most common tetrapod fossils in the Chinle Group, from specimens he found in Rio Arriba County. Here, AMNH = American Museum of Natural History, New York; CM = Carnegie Museum of Natural History, Pittsburgh; NMMNH = New Mexico Museum of Natural History, Albuquerque; UCMP = University of California Museum of Paleontology, Berkeley; USNM = National Museum of Natural History, Smithsonian Institution, Washington, D.C.

Cope's fossil localities

Although vertebrate paleontologists have long been aware of Cope's 1874 collection of Triassic vertebrates from north-central New Mexico, nobody has successfully relocated his original localities and documented their stratigraphic position. This is surprising because Simpson (1950) relocated with some accuracy Cope's collecting areas for early Eocene vertebrates near Regina, New Mexico, that were discovered soon after his Triassic collections were made.

The two principal sources of information on where Cope collected Triassic vertebrates in 1874 are his fieldbook in the archives of the American Museum of Natural History (New York) and his 1875 article describing the geology (p. 79–82) of the area near Gallina in Rio Arriba County. Critical is his published drawing (Cope, 1875, fig. 8) of his Triassic collecting area, reproduced here (Fig. 9).

Cope's fieldbook, this drawing and Cope's (1875) article led us to Cañada de la Tableta, north of Cerro Blanco in Rio Arriba County. Cope's (1875, fig. 8) drawing and our corresponding photograph (Fig. 9) were made/taken looking north from a point in the NW¼ NE¼ sec. 33, T24N, R1E toward the escarpment in the N½ sec. 5 and NW¼ sec. 6, T23N, R1E (both on the French Mesa, New Mexico 7.5-minute quadrangle map). Thus, the N½ of sec. 5 and NW¼ of sec. 6 is the location of Cope's 1874 fossils, including the type specimens of the reptile *Typothorax coccinarum* Cope, 1875 and the unionid bivalve *Unio cristonensis* Meek (in Cope, 1875) (Fig. 10).

Cope (1877, p. 9–10) provided the following evidence of the stratigraphic position of his collection:

> Besides the overlying sandstone bed ["ts" in Fig. 9, actually the Poleo Formation, mistakenly thought by Cope to overlie the red beds] the red marls are traversed below it by a conglomerate, which in some localities is of a bluish tint. At some points, it weathers to a gravel, *and near this horizon the vertebrate remains occur* [our italics]. At other points, it forms a very hard Potomac marble, containing pebbles of various colors (Cope, 1877, p. 9).

The "Potomac marble," from which the columns in the hallways of the U.S. Capitol are made, is limestone-cobble conglomerate of the Upper Triassic Leesburg Member of the Bull Run Formation quarried along the shores of the Potomac River (Gore et al., 1989). Along the northern flank of Cerro Blanco, within Cope's collecting area, is a conglomerate bed 2.3 m thick, of "bluish tint" on outcrop, that is within the Petrified Forest Formation (Figs. 4, 11); this bed probably is the "Potomac marble" referred to by Cope. At NMMNH locality 918 it contains coprolites and fragments of *Typothorax* that we consider topotypes of that taxon and which are described below.

Fossil plants

Significant megafossil plant specimens are restricted to the Agua Zarca Formation. The best localities are in El Cobre Canyon and were discovered by J. S. Newberry in 1859 (Ash, 1974). Later, J. W. Powell and the paleobotanist W. M. Fontaine also collected from these localities, which occur in two groups of now-abandoned copper mines, Minas de Pedro and Las Minas Jimmie. Several workers have described and redescribed these specimens. Ash (1974) reviewed the flora of the Agua Zarca Formation and listed the conifers *Brachyphyllum* sp., *Pagiophyllum newberryi* and *Araucarioxylon arizonicum* and the cycadophytes *Otozamites macombi*, *O. powelli* and *Zamites occidentalis*. We note that Ash (1974, fig. 2) is incorrect in showing the Poleo Formation lying directly on the Agua Zarca Formation in El Cobre Canyon (Fig. 4). Hunt and Lucas (1990, fig. 2A) illustrated a poorly preserved specimen of *Zamites* from the Petrified Forest Formation near San Ysidro. Litwin (1986) and Litwin et al. (1991) described palynomorphs from the Petrified Forest and Rock Point Formations. These palynomorphs indicate a Norian age for the Petrified Forest and Rock Point Formations, an age assignment consistent with vertebrate biochronology (see below).

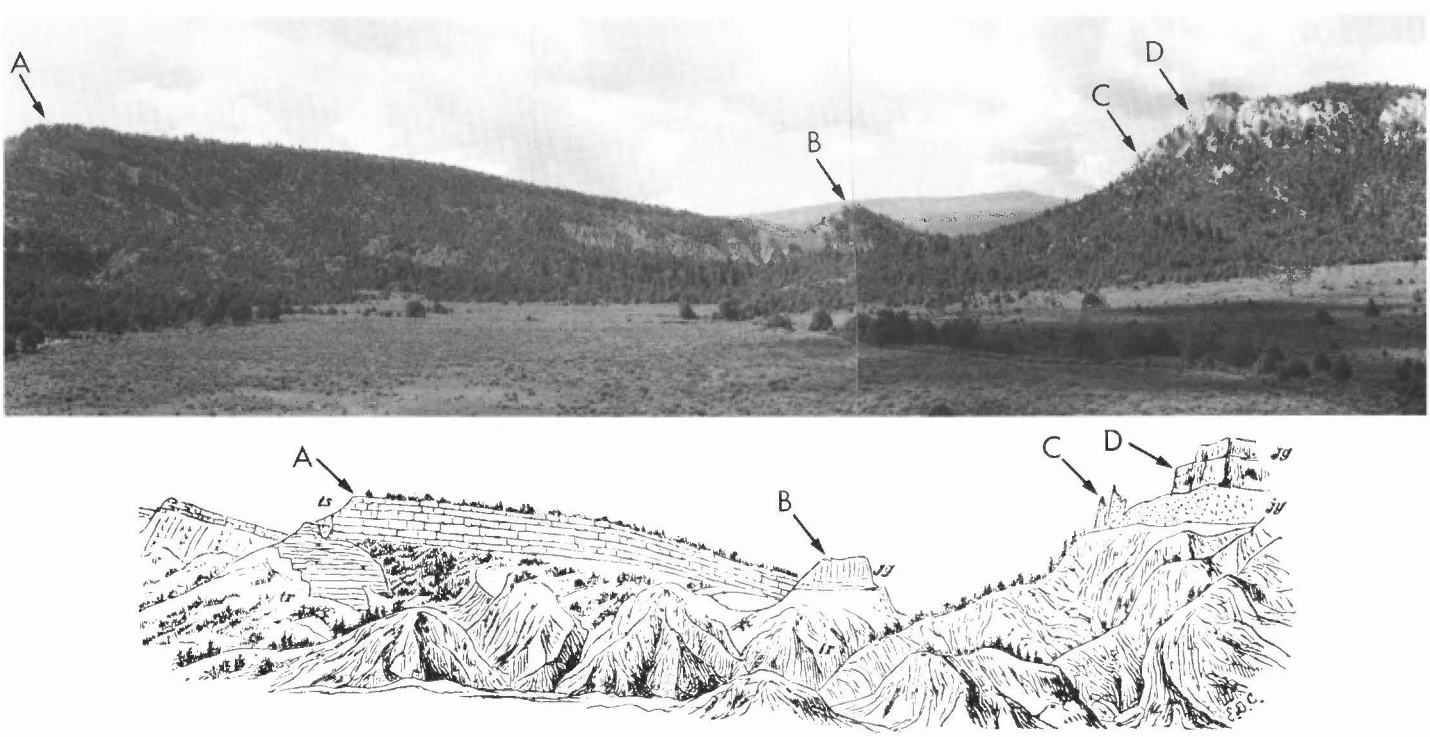


FIGURE 9. Photograph (above) of Triassic and Jurassic strata exposed on northern end of Cerro Blanco and Cope's (1875, fig. 8) drawing (below) of the same location. A, B, C and D are corresponding points on the photograph and the drawing.

Unionid bivalves

In 1874, Cope found fragmentary valves of unionid bivalves (Fig. 12) in the Petrified Forest Formation, which he gave to F. B. Meek who recognized three taxa. Meek (in Cope, 1875, p. 83) named one of these forms *Unio cristonensis* but did not designate a holotype. Subsequent workers have failed to designate a lectotype (though White, 1883, pl. 3, fig. 5 did illustrate a "well preserved" specimen). We designate as lectotype one of the more complete valves (Fig. 12C–D) that is one of the syntypes of *U. critonensis*, all of which are catalogued as USNM 30731. We are not able to identify with certainty the specimen White (1883) illustrated. The other two names for Cope's unionids introduced by Meek (in Cope, 1875, p. 84) are *Unio gallinensis* and *Unio terraerubrae*. Type specimens of these species have never been unambiguously identified, so we consider these taxa nomina dubia.

Other unionids have been found subsequently in north-central New Mexico, but these specimens are restricted to the Petrified Forest Formation. None of them are identifiable below the generic level (e.g., NMMNH P-11064).

Systematic vertebrate paleontology

Class **Osteichthyes**
Order **Redfieldiiformes**
Family **Redfieldiidae**
aff. ***Synorichthys***

Referred specimens—AMNH 5719, partial skeleton (Rock Point Formation, *Rioarribasaurus* quarry).

Discussion—Schaeffer (1967, fig. 15) noted resemblances between this partial skeleton and *Synorichthys* in the opercular and cheek elements and the ornamentation of the dermal elements.

Order **Crossopterygii**
Family **Coelacanthidae**
cf. ***Chinlea***

Referred specimens—AMNH 5657, fragmentary skull and cleithrum (Rock Point Formation, *Rioarribasaurus* quarry).

Discussion—Schaeffer (1967) assigned this specimen to *Chinlea sorensei*. However, like many other Chinle Group coelacanth specimens, AMNH 5657 was referred to this taxon simply because it is the only species known from the Late Triassic of the western United States. Thus, we assign this specimen more tentatively to cf. *Chinlea*.

Order **Dipnoi**
Family **Ceratodontidae**
Arganodus dorotheae (Case)

Referred specimen—NMMNH P-14382 (Hunt and Lucas, 1990a, fig. 2B), upper toothplate (Petrified Forest Formation, NMMNH locality 371).

Discussion—This specimen represents a pterygoid or pterygopalatine toothplate because the mesial side of the first cusp is not visible in occlusal view and because the lingual and labial profiles decline posteriorly (Hunt and Lucas, 1990a).

Class **Amphibia**
Order **Temnospondyli**
Family **Metoposauridae,** genus indeterminate
Fig. 13A

Referred specimens—NMMNH P-11001, skull fragments (Salitral Formation, NMMNH locality 913); NMMNH P-14383, interclavicle fragment; NMMNH P-14384, dorsal centrum (Petrified Forest Formation, NMMNH locality 371).

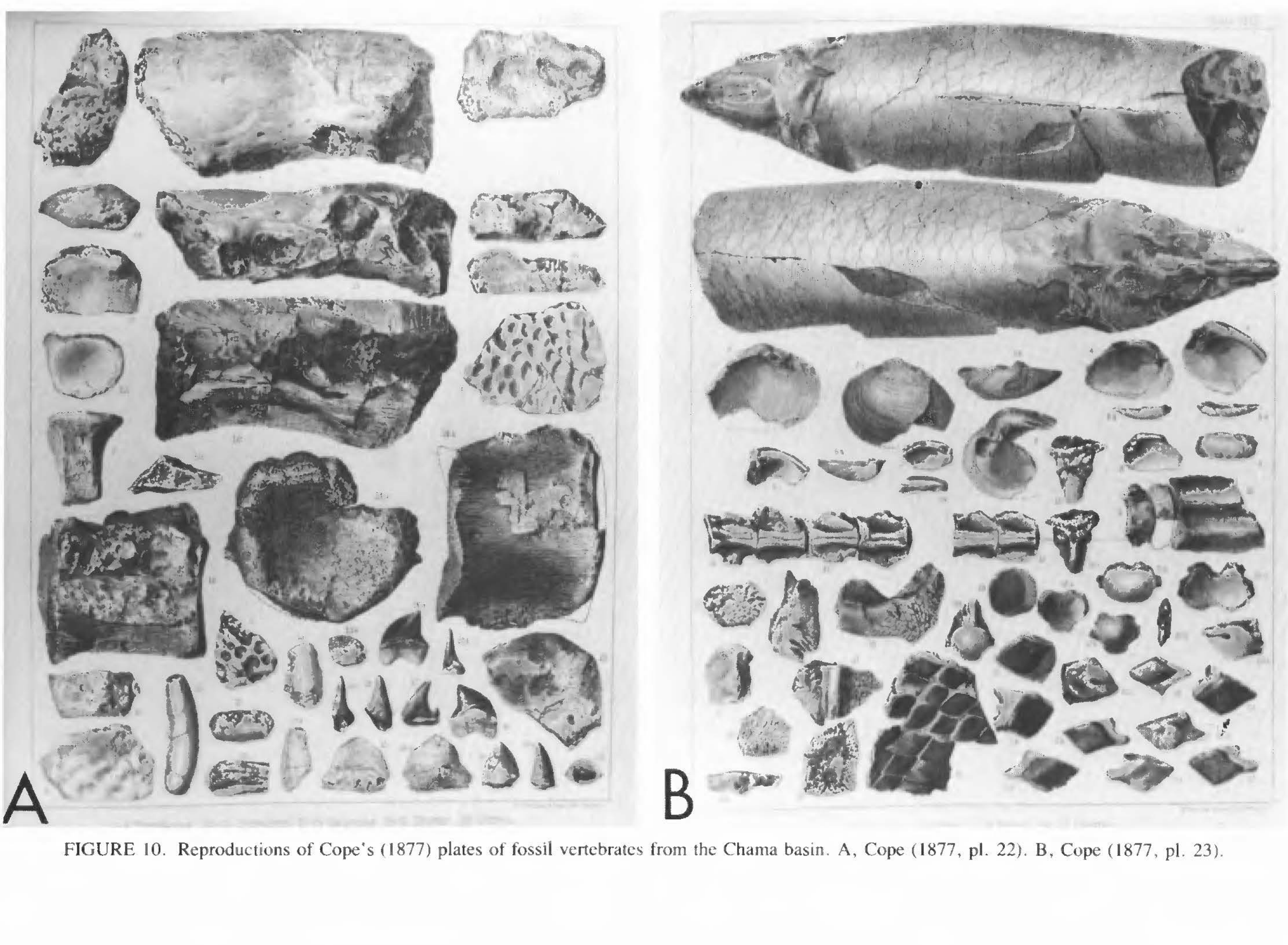


FIGURE 10. Reproductions of Cope's (1877) plates of fossil vertebrates from the Chama basin. A, Cope (1877, pl. 22). B, Cope (1877, pl. 23).

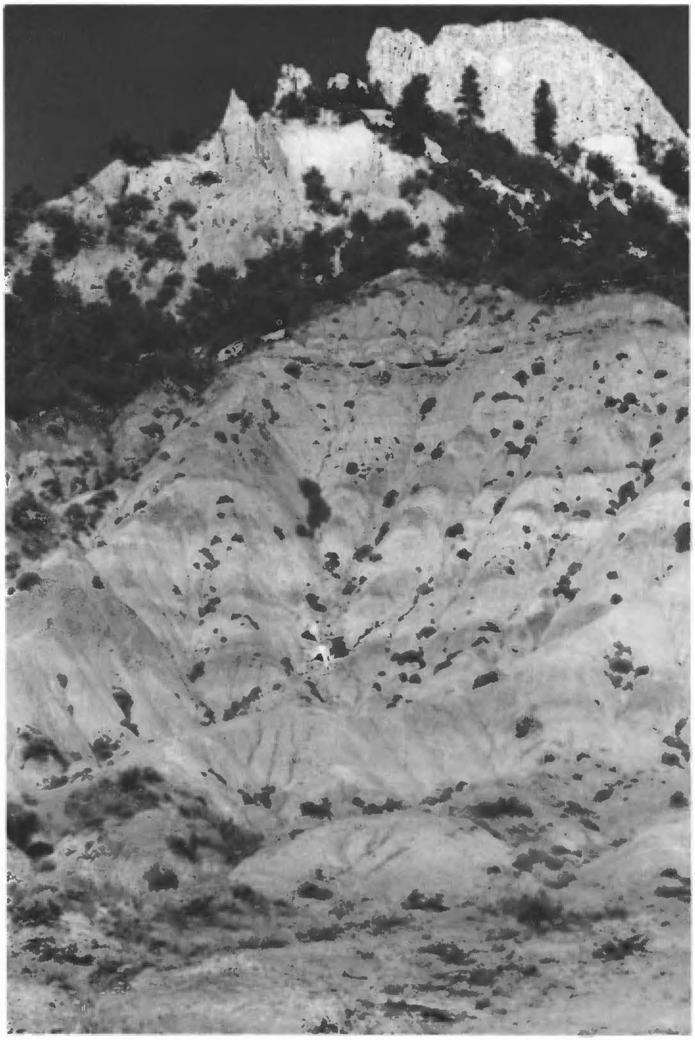


FIGURE 11. Slope developed in Upper Triassic Petrified Forest Formation, overlain by cliffs of Middle Jurassic Entrada Sandstone and Todilto Formation on northern end of Cerro Blanco. The people are at the stratigraphic level of Cope's type locality of *Typothorax*.

Discussion—These fragments represent a large metoposaurid amphibian with a skull length in excess of 25 cm. These specimens are not generically diagnostic. However, the only North American genera with such large skull size are *Metoposaurus* and *Buettneria* (Hunt, 1992).

Class **Reptilia**
Subclass **Diapsida**
Division **Archosauria**
Subdivision **Crurotarsi**
Family **Phytosauridae**
Pseudopalatus pristinus Mehl
Fig. 13G

Referred specimens—NMMNH P-11076, skull lacking tip of rostrum and skull roof anterior to orbits (Petrified Forest Formation, NMMNH locality 911); UCMP 34249, skull; UCMP 27231, skull lacking anterior rostrum; UCMP 34251, skull lacking rostrum (Petrified Forest Formation; UCMP V2816, Canjilon quarry).

Discussion—*Pseudopalatus pristinus* is common in the Canjilon quarry, which is in the upper part of the Petrified Forest Formation. NMMNH locality 911, which also contains this taxon, is low in the Petrified Forest Formation. Lawler (1976) referred all the Canjilon quarry phytosaurs to *Rutiodon tenuis*. Subsequently, Ballew (1989) recognized two taxa in the quarry, *Pseudopalatus pristinus* and *P. buceros*.

Pseudopalatus buceros (Cope)

Referred specimens—UCMP 34246, skull and lower jaws; UCMP 27228, skull; UCMP 34250, skull (Petrified Forest Formation, UCMP V2816, Canjilon quarry).

Discussion—Ballew (1989) referred several specimens from the Canjilon quarry to *Pseudopalatus buceros*. The locality of the holotype of *P. buceros* is not known with certainty, although it did come from New Mexico, possibly from near Cerro Blanco. The skulls from the Canjilon quarry differ from the holotype of this taxon in having more elevated external nares and a less well developed rostral crest.

New genus and species

Referred specimen—CM, unnumbered, skull (Rock Point Formation, *Rioarribasaurus* quarry).

Discussion—This skull represents a new genus and species and is characterized by supratemporal fenestrae that are obscured in dorsal view and by a distinct rostral crest. This genus is also known from the Redonda and Travesser Formations of east-central and northeastern New Mexico, respectively (Hunt, 1990). It will be described elsewhere.

Phytosauridae, indet.
Figs. 14A–E

Referred specimens—Petrified Forest Formation: NMMNH P-11030, dorsal centrum (NMMNH locality 901); NMMNH P-11025, radius; NMMNH P-11042, partial pubis; NMMNH P-11011, scute fragments (NMMNH locality 903); NMMNH P-11024, scute fragments (NMMNH locality 912); NMMNH P-11023, jaw fragments (NMMNH locality 914); NMMNH P-11015, scute fragments, NMMNH P-18200, indeterminate fragments (NMMNH locality 918); NMMNH P-11010, scute fragments, NMMNH P-11058, partial cervical vertebra, NMMNH P-11059, fragment of dorsal centrum (NMMNH locality 919); USNM 2585 (in part), jaw fragment, partial centrum, USNM 2592, tooth. Salitral Formation: NMMNH P-11014, scute fragment, NMMNH P-11021, teeth (NMMNH locality 913).

Discussion—Indeterminate specimens constitute the majority of phytosaur specimens from all formations except the Rock Point. Cope (1875, 1877) incorrectly identified a posterior phytosaur tooth (USNM 2592) as pertaining to a dinosaur.

Family **Stagonolepididae**
Longosuchus sp.
Fig. 13C

Referred specimens—NMMNH P-11005, partial paramedian scute (Hunt and Lucas, 1990a, fig. 3I–J), from Salitral Formation, NMMNH locality 913.

Discussion—This scute has the typical sigmoidal shape in lateral view that is characteristic of this species. This identification is confirmed by the prominent boss and the radial ornamentation apparent on the dorsal surface (Hunt and Lucas, 1990b).

Typothorax coccinarum Cope
Fig. 14F–Q

Referred specimens—Petrified Forest Formation: MCZ 1487, 1488, partial skeletons (Canjilon quarry); NMMNH P-11026, paramedian scute fragments; P-11002, paramedian scute fragments (NMMNH locality 905); NMMNH P-11027, paramedian scute fragments (NMMNH locality 906); NMMNH P-11004, paramedian scute fragments (NMMNH locality 911); NMMNH P-11057–11063, paramedian scute fragments (NMMNH locality 919); UCMP 34255, 34248, 34259, partial skeletons (UCMP locality V2816, Canjilon quarry); scute fragments (NMMNH locality 918); USNM 2585, lectotype specimens of *Typothorax coccinarum;* 2586, syntype of *Typothorax coccinarum;* and the following topotypes of *Typothorax coccinarum*, NMMNH P-18197, NMMNH P-18199, NMMNH P-18201 (scute fragments).

Discussion—Cope (1875, p. 84) named *Typothorax coccinarum* for fragments of what we now recognize to be an indeterminate phytosaur and scute fragments of a distinct aetosaur. Cope (1877, plates 22–23; Figs. 14A–B, H–M, E) illustrated these specimens. Later workers have

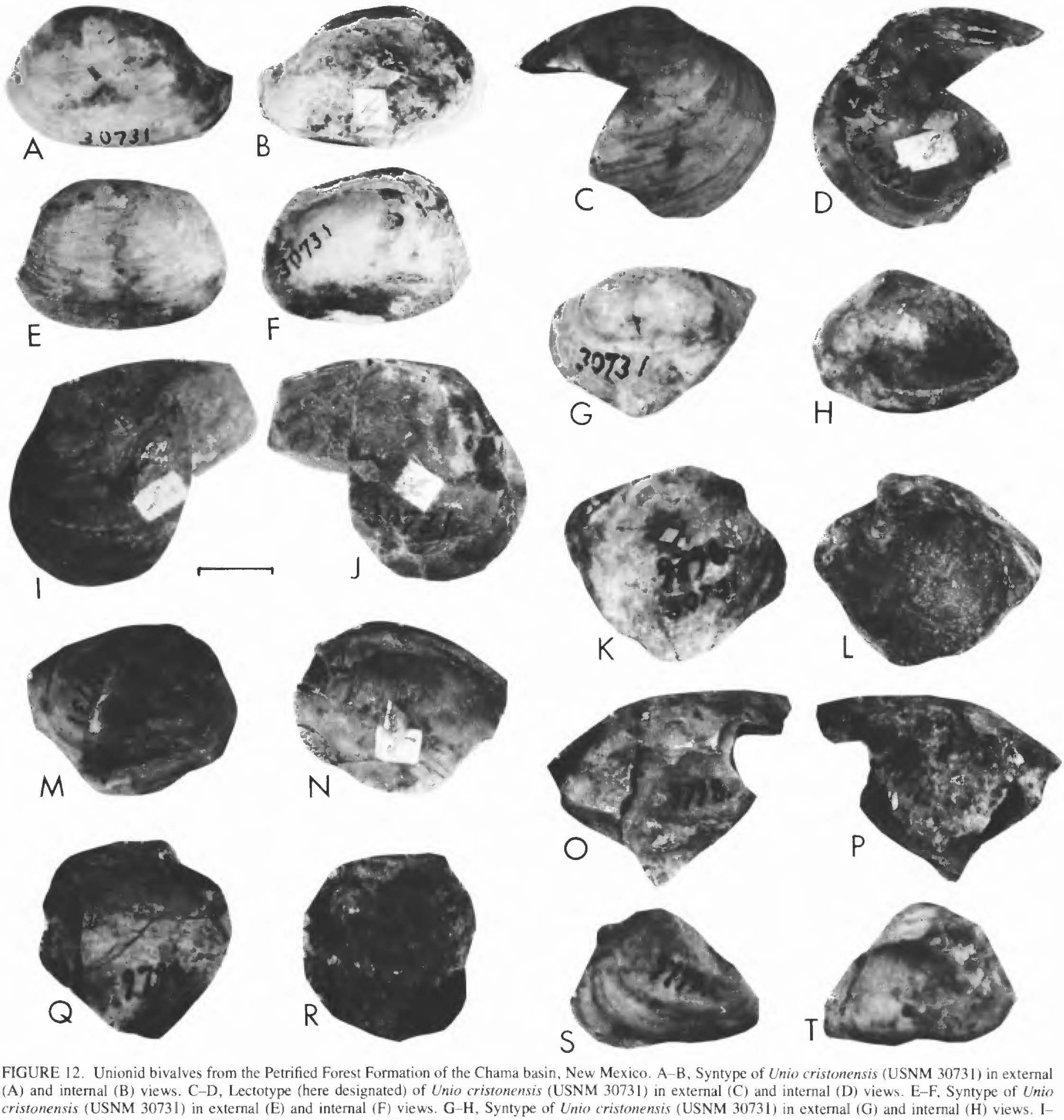


FIGURE 12. Unionid bivalves from the Petrified Forest Formation of the Chama basin, New Mexico. A–B, Syntype of *Unio cristonensis* (USNM 30731) in external (A) and internal (B) views. C–D, Lectotype (here designated) of *Unio cristonensis* (USNM 30731) in external (C) and internal (D) views. E–F, Syntype of *Unio cristonensis* (USNM 30731) in external (E) and internal (F) views. G–H, Syntype of *Unio cristonensis* (USNM 30731) in external (G) and internal (H) views. I–J, Syntype of *Unio cristonensis* (USNM 30731) in external (I) and internal (J) views. K–L, Syntype of *Unio cristonensis* (USNM 30731) in external (K) and internal (L) views. M–N, Syntype of *Unio cristonensis* (USNM 30731) in external (M) and internal (N) views. O–P, Indeterminate unionid (USNM 9798) in external (O) and internal (P) views. Q–R, Indeterminate unionid (USNM 9798) in external (Q) and internal (R) views. S–T, Indeterminate unionid (USNM 9798) in external (S) and internal (T) views. Scale bars are 1 cm.

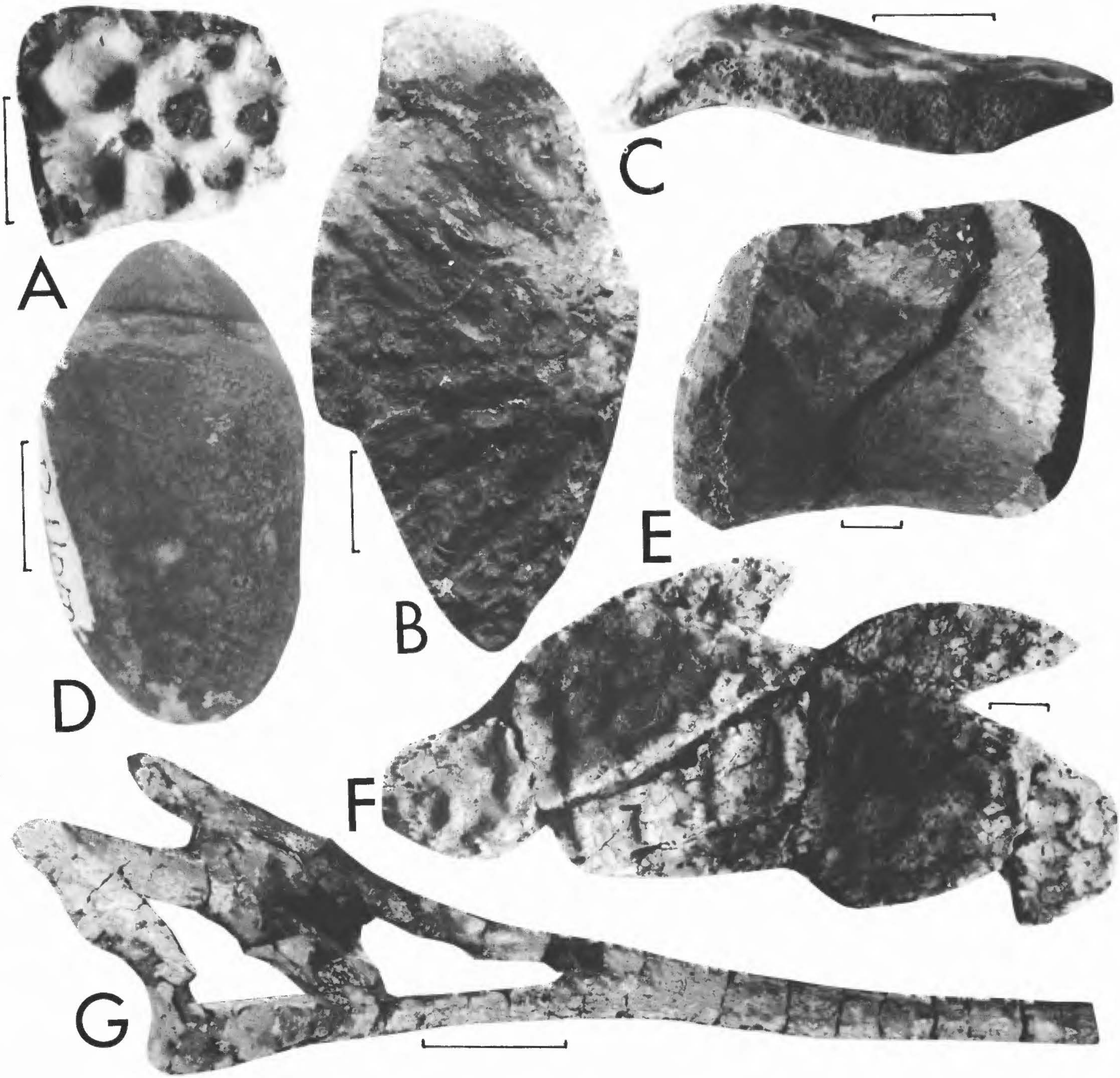
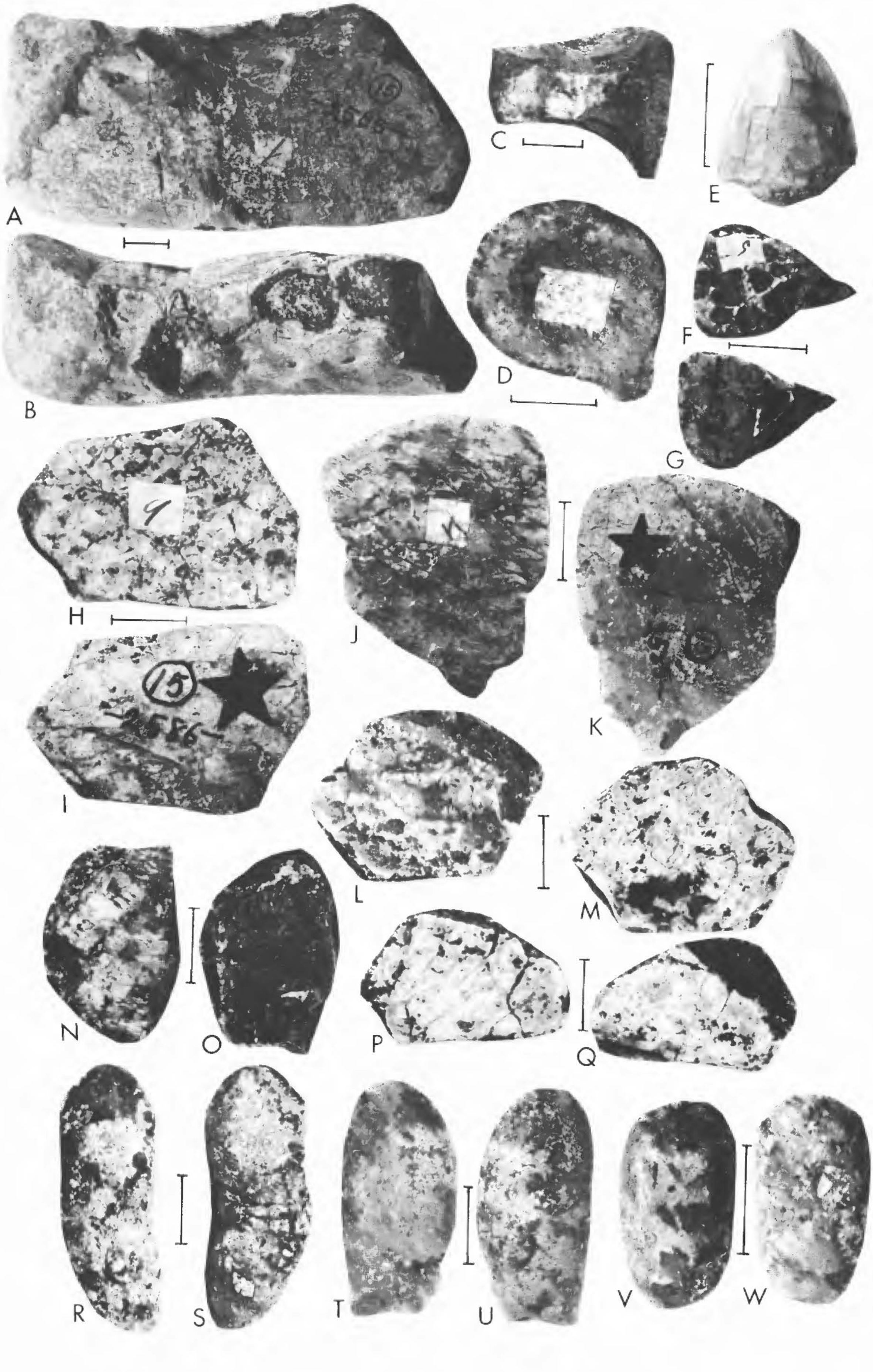


FIGURE 13. Vertebrate fossils from the Chinle Group of the Chama basin. All specimens except C are from the Petrified Forest Formation; C is from the Salitral Formation. A, Cranial fragment of indeterminate large metoposaurid amphibian (NMMNH P-11001) in dorsal view. B, Paramedian scute fragment of the stagonolepidid *Paratypothorax* (NMMNH P-11037) in dorsal view. C, Paramedian scute of stagonolepidid *Longosuchus* (NMMNH P-11005) in lateral view. D, Vertebrate coprolite (NMMNH P-11050) in lateral view. E, Dorsal centrum of indeterminate phytosaur (NMMNH P-11044) in lateral view. F, Paramedian scute of the stagonolepidid *Typothorax coccinarum* (NMMNH P-11004) in dorsal view. G, Skull of phytosaur *Pseudopalatus pristinus* (NMMNH P-11076) in dorsolateral view. Scale bars are 1 cm for A–D and 10 cm for G, E–F are natural size.

FIGURE 14. Vertebrate fossils from NMMNH locality 918, Petrified Forest Formation of the Chama basin, New Mexico. A–B, Premaxillary fragment of indeterminate phytosaur (syntype of *Typothorax coccinarum*, USNM 2585) in lateral (A) and ventral (B) views. C–D, Caudal centrum of indeterminate ?stagonolepidid (syntype of *Typothorax coccinarum*, USNM 2585) in ventral (C) and posterior (D) views. E, Posterior tooth of indeterminate phytosaur (USNM 2592) in lateral view. F–K, Lectotype fragments of paramedian scutes of stagonolepidid *Typothorax coccinarum* (USNM 2585) in dorsal (F, H, J) and ventral (G, I, K) views. L–Q, Topotype fragments of paramedian scutes of stagonolepidid *Typothorax coccinarum*; L, M, dorsal and ventral views of NMMNH P-18197; N–O, dorsal and ventral views of NMMNH P-18199; P–Q, ventral and dorsal views of NMMNH P-18201. R–W, Vertebrate coprolites NMMNH P-18198 (R, S), NMMNH P-18198 (T, U), and NMMNH P-18198 (V, W) in two lateral views each. Scale bars are 1 cm, A–B are natural size.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restricted the name to refer to the aetosaur specimens. Cope (1875) did not designate a holotype of *Typothorax coccinarum*, but Long and Ballew (1985, p. 53) designated USNM 2585 (scutes, not jaw fragment) as the lectotype of *Typothorax coccinarum* (Fig. 14H–I; Cope, 1877, pl. 22.4; Figs. 11H–I, F). We also recognize NMMNH fragments of scutes from the same locality (NMMNH P-18197, 18199, 18201) as topotypes of *Typothorax coccinarum* (Fig. 14L–Q).

Paratypothorax sp.
Fig. 13B

Referred specimens—NMMNH P-11037, paramedian scute fragment (Petrified Forest Formation, NMMNH locality 900).

Discussion—This fragment of a paramedian scute is assigned to *Paratypothorax* on the basis of its radial ornamentation on the dorsal surface and its thinness and flatness.

Family **Rauisuchidae**
Postosuchus kirkpatricki Chatterjee

Referred specimens—CM uncatalogued, complete skeleton (Rock Point Formation, *Rioarribasaurus* quarry).

Discussion—A complete skeleton of a rauisuchian in CM has been identified by R. A. Long (oral comm. 1988) as *Postosuchus kirkpatricki*.

Order **Saurischia**
Infraorder **Ceratosauria**
Family **Podokesauridae**
Rioarribasaurus colberti Hunt and Lucas

Referred specimens—AMNH 7223, 7224 (holotype), complete skeletons and many more specimens including complete skeletons (Rock Point Formation, *Rioarribasaurus* quarry).

Discussion—Abundant skeletons from the *Rioarribasaurus* quarry have been recently monographed by Colbert (1989). These specimens were believed to be *Coelophysis bauri* by most authors (e.g., Colbert, 1950, 1964, 1974, 1989; Rowe and Gauthier, 1990) but have recently been demonstrated to represent a new taxon (Hunt and Lucas, 1991).

Podokesauridae, genus indeterminate

Referred specimens—Various AMNH specimens described by Huene (1915) and listed by Padian (1986), from an unknown locality, Petrified Forest Formation.

Discussion—Cope (1887a, b, 1889) assigned several specimens of indeterminate dinosaurs to the genus *Coelophysis*. These specimens represent indeterminate ceratosaurian(s) or theropod(s) (Hunt and Lucas, 1991).

Other taxa from the *Rioarribasaurus* quarry

Several new taxa of archosaurs from the *Rioarribasaurus* quarry are currently being studied by various workers. These include a sphenosuchian and more than one crurotarsan.

Vertebrate coprolites
Figs. 13D, 14R–W

Referred specimens—Petrified Forest Formation: NMMNH P-11041 (NMMNH locality 911); NMMNH P-11035 (NMMNH locality 920); NMMNH P-11045 (NMMNH locality 909); NMMNH P-11046 (NMMNH locality 912); NMMNH P-110503 (NMMNH locality 919); USNM 2586, NMMNH P-18198, NMMNH P-18198, NMMNH P-18198 (NMMNH locality 918). Salitral Formation: NMMNH P-11001, P-11005 (NMMNH locality 913).

Discussion—Vertebrate coprolites are common in all formations.

CORRELATION

The vertebrate faunas and the lithostratigraphic sequence from the Upper Triassic strata in north-central New Mexico allow correlation of the Chinle Group in the Chama basin and adjacent areas with Upper Triassic strata exposed elsewhere in New Mexico (Fig. 15). Vertebrate taxa distinguish superposed faunas B, C and D of Lucas (1992) in the Chinle Group of the Chama basin.

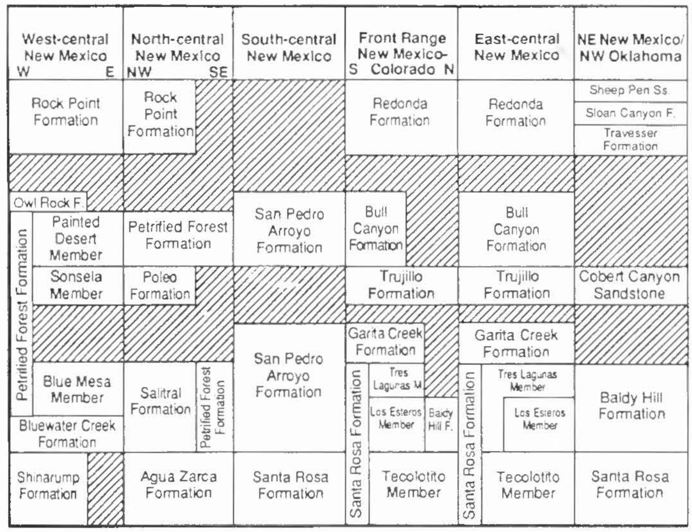

FIGURE 15. Correlation of the Upper Triassic Chinle Group in north-central New Mexico with some other Upper Triassic strata (after Lucas, 1992).

The lowest fauna occurs in the Salitral Formation and includes the aetosaur *Longosuchus*, which is restricted to late Carnian strata (Hunt and Lucas, 1990b). This fauna also includes a large metoposaurid that represents either *Metoposaurus* or *Buettneria*. These taxa are common in late Carnian strata and are rare in Norian strata (Hunt, 1992; Hunt and Lucas, 1992). Thus, the Salitral fauna is of late Carnian age. The presence of a large metoposaurid in the lower Petrified Forest Formation near San Ysidro suggests that it is correlative with the Salitral (Hunt and Lucas, 1990a).

The Petrified Forest Formation of the Chama basin includes three age-diagnostic taxa, the aetosaur *Typothorax coccinarum* and the phytosaurs *Pseudopalatus pristinus* and *P. buceros*. These taxa are restricted to strata of early-middle Norian age (Long and Ballew, 1985; Hunt and Lucas, 1990a; Hunt, 1990).

The Rock Point fauna includes a new genus of phytosaur that also occurs in the Travesser Formation of northeastern New Mexico and the Redonda Formation of east-central New Mexico (Hunt, 1990). A diverse body of evidence suggests that these strata are of late Norian/Rhaetian age, including the fact that the new phytosaur is more derived than typical middle Norian taxa (Hunt, 1991).

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APPENDIX—MEASURED STRATIGRAPHIC SECTIONS

The lithologies of the measured stratigraphic sections in Fig. 4 are described here. Rock colors follow Goddard et al. (1984).

Nacimiento mine

Measured in the NW¼ SE¼ and N½ SW¼ sec. 1, T20N, R1W, Sandoval County, New Mexico. Strata dip 23° to due west.

unit	lithology	thickness (m)
	Chinle Group:	
	Petrified Forest Formation:	
18	Silty mudstone: pale olive (10 Y 6/2); bentonitic; calcareous.	not measured
17	Sandy siltstone and mudstone: grayish red (10 R 4/2); noncalcareous; sandier portions are ripple laminar.	3.6
	Poleo Formation:	
16	Sandstone: pale olive (10 Y 6/2); very fine grained; subrounded and well sorted; micaceous quartzarenitic; trough crossbedded with ripple marks; top surface is ripple laminar; calcareous; weathers to a rounded cliff.	4.1
15	Mudstone: grayish red (10 R 4/2); has some lenses of sandstone like unit 14; very calcareous.	13.1
14	Sandstone, siltstone and conglomerate: sandstone is pale greenish yellow (10 Y 8/2), very fine grained, subrounded, well sorted, noncalcareous, micaceous quartzarenite; siltstone is light olive gray (5 Y 5/2) and very slightly calcareous; conglomerate is calcrete pebbles up to 5 cm diameter that are pale olive (10 Y 6/2) and very calcareous in a sandstone matrix like that described above; sandstone is trough crossbedded and multistoried with siltstone tops overlain by conglomeratic channel bases every 1–2 meters.	24.3
13	Conglomerate: grayish yellow green (5 GY 7/2); calcrete clasts and minor black chert up to 1 cm diameter; matrix is very fine-fine grained, subangular, moderately sorted, micaceous quartzarenite; calcareous; massive.	0.9
	unconformity	
	Salitral Formation:	
12	Mudstone: pale green (5 G 7/2); slightly calcareous.	0.8
11	Mudstone: dark reddish brown (10 R 3/4); slightly calcareous; very bentonitic; unit forms strike valley that includes road to Nacimiento copper mine and is partly covered by alluvium.	29.7
10	Mudstone: grayish red purple (5 RP 4/2); noncalcareous; very bentonitic; much covered by alluvium; a fault is evident in this unit accounting for its abnormal(?) thickness.	30.5
9	Mudstone and muddy sandstone: grayish red purple (5 RP 4/2); sandstone is very fine grained, subangular, well sorted litharenite; sandstone is trough crossbedded in 1–2 m beds; noncalcareous.	5.2
	Agua Zarca Formation:	
8	Sandstone: pale yellowish brown (10 YR 6/2) and very pale orange (10 YR 8/2); very fine to very coarse grained; subangular and poorly sorted; micaceous quartzarenitic; contains pebbles of white quartzite and very pale green (10 G 8/2) siltstone up to 1 cm in diameter in trough bottoms; noncalcareous; trough crossbedded; prominent scour surfaces about every 3.0 m; fines upward.	13.3
7	Siltstone: greenish gray (5 GY 6/1); noncalcareous.	0.1
6	Sandstone: grayish orange (10 YR 7/4); very fine-medium grained; subrounded and poorly sorted; quartzarenitic; noncalcareous; trough crossbedded; a major scour surface about in middle of unit.	6.1
5	Siltstone: greenish gray (5 GY 6/1); noncalcareous.	1.3
4	Conglomerate: matrix is yellowish gray (5 Y 8/1) very fine-medium grained, subrounded, moderately sorted quartzose sandstone; clasts are white, pink, red and black chert and quartzite pebbles up to 3 cm in diameter; noncalcareous; trough crossbedded; fines upward.	1.8
3	Conglomerate, sandstone and siltstone: conglomerate has matrix of grayish green (5 GY 6/1) fine-coarse grained, subrounded, poorly sorted, noncalcareous quartzose sandstone and pebbles of white and black quartzite up to 3 cm in diameter; sandstone is yellowish gray (5 Y 8/1), very fine grained, subrounded, well sorted, noncalcareous and quartzose; siltstone is pale green (5 G 7/2), noncalcareous and sandy; sandstone is ledgy; trough crossbedded.	3.0
	unconformity	
	Yeso Formation (Permian):	
2	Sandstone: pale reddish brown (10 R 5/4) with white (N 9) speckles; very fine-fine grained; subrounded and moderately sorted; noncalcareous; litharenitic; low angle trough crossbeds; ledgy.	2.0
1	Sandstone: pale red (10 R 6/2) with white (N 9) speckles; fine grained; subrounded and poorly sorted; litharenitic; noncalcareous; trough crossbedded.	not measured

Cerro Blanco

Measured in the NE¼ sec. 4, T23N, R1E, Rio Arriba County.

unit	lithology	thickness (m)
	San Rafael Group:	
	Entrada Sandstone:	
21	Sandstone: pale green yellow (10 Y 8/2); fine grained; subrounded; well sorted; noncalcareous; trough crossbedded; cliff former.	not measured
	unconformity	
	Chinle Group:	
	Petrified Forest Formation:	
18	Mudstone: pale blue (5 B 5/6); calcareous.	4.6
17	Silty mudstone: same lithology and color as unit 11.	5.9
16	Mudstone: grayish red purple (5 RP 4/2) and grayish yellow green (5 GY 7/2); slightly silty; very calcareous.	0.6
15	Silty mudstone: same lithology and color as unit 11.	11.4

14	Silty mudstone: mottled moderate reddish brown (10 R 4/6) and grayish yellow green (5 GY 7/2); moderately calcareous.	0.35
13	Silty mudstone: same lithology and color as unit 11.	2.9
12	Silty sandstone: moderate reddish brown (10 R 4/6); very fine grained; subangular to subrounded; well sorted; quartzose; much hematite; noncalcareous.	0.6
11	Silty mudstone: same lithology and color as unit 9.	4.9
10	Muddy sandstone: moderate reddish brown (5 R 5/4) and pale green (5 G 7/2); very fine grained; subangular; well sorted; quartzose; platy and lenticular.	1.8
9	Silty mudstone: pale reddish brown (10 R 5/4); very calcareous.	4.9
8	Mudstone, grades up to sandy siltstone: mudstone is grayish red purple (5 RP 4/2) and noncalcareous; sandy siltstone is grayish red purple (5 RP 4/2) to grayish yellow green (5 GY 7/2); sand is medium grained, subrounded, quartzose and very calcareous.	3.4
7	Siltstone: pale reddish brown (10 R 5/4); very calcareous.	11.9
6	Sandstone and clay-pebble conglomerate: dusky red (5 R 3/4) to moderate yellow green (5 GY 7/4); sandstone is same lithology as unit 3; very calcareous; conglomerate clasts are calcrete, highly calcareous; conglomerate has crude trough crossbeds; sandstone is 15-cm-thick laminar bed 1 m from base; unit 8 is laterally discontinuous and pinches out 10 m laterally; NMMNH locality 918, type locality of *Typothorax coccinarum*, is in conglomerate.	2.0
5	Muddy siltstone, grades up to silty mudstone: muddy siltstone is pale olive (10 Y 6/2) and highly calcareous; silty mudstone is pale reddish brown (10 R 5/4) and noncalcareous.	8.1
4	Mudstone: same lithology and color as unit 2.	5.6
3	Siltstone and sandstone: dark reddish brown (10 R 3/4); sandstone is very fine grained, quartzose, with mica flakes; slightly calcareous.	3.4
2	Mudstone: pale red purple (5 RP 6/2) with some mottling of grayish yellow green (5 GY 7/2); slightly silty; very calcareous.	1.4
1	Mudstone: yellowish gray (5 GY 7/2) and pale reddish brown (10 R 5/4); bentonitic; very calcareous.	5.0

Mesa Montosa

Measured in the NW$^1/_4$ SE$^1/_4$ sec. 36, T23N, R2E, Rio Arriba County.

unit	lithology	thickness (m)
	Chinle Group:	
	Salitral Formation:	
11	Sandy mudstone: light greenish gray (5 G 8/1); noncalcareous.	1.5
	Agua Zarca Formation:	
10	Sandstone: light greenish gray (5 GY 8/1); fine-medium grained; subrounded; moderately sorted; sublitharenitic; noncalcareous; ripple laminar and bioturbated; caps ledge.	0.1
9	Sandstone: grayish blue (5 PB 5/2); fine-coarse grained; subrounded; poorly sorted; litharenitic; noncalcareous; trough crossbedded.	1.7
8	Mudstone: mottled grayish red purple (5 RP 4/2) and dusky yellow (5 Y 6/4); noncalcareous.	2.7
7	Sandstone: grayish red purple (5 RP 4/2); fine-medium grained; subrounded; moderately sorted; micaceous litharenitic; trough crossbedded; some angular pebbles of chert and quartzite.	2.0
	unconformity	
	mottled strata:	
6	Sandy mudstone and siltstone: mottled very dusky red purple (5 RP 2/2) and moderate reddish orange (10 R 6/6); secondary gypsum platelets; forms a slope.	2.4
5	Sandstone: grayish red purple (5 RP 4/2); medium grained; subrounded; well sorted; lithic wacke; noncalcareous; bioturbated with a hint of trough crossbeds; some quartzite-pebble gravels; forms a ledge.	0.8
4	Siltstone: mottled very dusky purple (5 P 2/2) and light olive gray (5 Y 5/2); noncalcareous.	1.7
3	Sandy mudstone and siltstone: mottled grayish purple (5 P 4/2) and dusky yellow (5 Y 6/4); sandy nodules are grayish yellow green (5 GY 7/2) and light brown (5 GY 5/6); noncalcareous.	1.4
2	Silty sandstone: mottled very dusky red purple (5 RP 2/2), dusky yellow (5 Y 6/4), moderate reddish brown (10 R 4/6) and pale greenish yellow (10 Y 8/2); very fine-fine grained; subrounded-subangular; moderately sorted; arkosic; noncalcareous; massive; ledge former.	0.8
	Cutler Formation:	
1	Muddy sandstone: moderate reddish brown (10 R 4/6) with pale greenish yellow (10 Y 8/2) reduction spots; fine-medium grained; subrounded; poorly sorted; arkosic; noncalcareous; massive.	not measured

Type Agua Zarca and Salitral Formations

Measured in the SE$^1/_4$ sec. 36, T23N, R2E. Strata dip 12° to due west.

unit	lithology	thickness (m)
	Chinle Group:	
	Poleo Formation:	
24	Sandstone: yellowish gray (5 Y 7/2), weathers grayish olive green (5 GY 3/2); fine grained; subrounded; well sorted; calcareous; trough crossbedded; forms a cliff; top of unit a stripped surface here.	5.6
23	Sandstone: grayish yellow (5 Y 8/4); very fine grained; subrounded; well sorted; sublitharenitic; very calcareous; platy with small trough crossbeds; liesegang bands.	1.2
22	Conglomerate: same colors and lithology as unit 18.	2.3
21	Sandstone and conglomerate: sandstone is pale olive (10 Y 6/2); weathers dark yellowish brown (10 YR 4/2); very fine-fine grained; subrounded; well sorted; litharenitic; very calcareous; conglomerate is same colors and lithology as unit 18; in graded trough beds with sandstone at top.	3.0
20	Conglomerate: same colors and lithology as unit 18.	1.7
19	Sandstone: dusky yellow (5 Y 6/4); very fine-fine grained; subrounded; well sorted; litharenitic; noncalcareous; trough crossbedded.	0.2
18	Conglomerate: matrix is pale olive (10 Y 6/2); very fine-medium grained, angular/subangular, poorly sorted, very calcareous, subarkosic; clasts are red, white, pink and black chert; faint trough crossbeds.	1.1
17	Sandstone and conglomerate: sandstone is yellowish gray (5 Y 7/2), very fine grained, subrounded, well sorted, very calcareous, micaceous litharenitic; conglomerate consists of pale olive (10 Y 6/2) clasts of nodular calcrete up to 15 cm in diameter; conglomerate forms base of scours in trough-crossbedded sandstone.	1.5
	unconformity	
	Salitral Formation:	
16	Muddy sandstone: light greenish gray (5 GY 8/1); very fine-fine grained; subarkosic; subrounded; moderately sorted; litharenitic; massive.	3.6
15	Mudstone: same color and lithology as unit 13.	5.6
14	Mudstone: grayish red (5 R 4/2); noncalcareous.	3.0
13	Mudstone: grayish red purple (5 RP 4/2); noncalcareous.	2.4
12	Sandstone: grayish red purple (5 RP 4/2); fine-medium grained; subrounded; moderately sorted; litharenitic; noncalcareous; small trough crossbeds.	1.2
11	Mudstone: grayish purple (5 P 4/2); noncalcareous.	3.6
10	Siltstone: mottled pale reddish purple (5 RP 6/2) and grayish yellow green (5 GY 7/2); paleosol.	0.8
	Agua Zarca Formation:	
9	Conglomeratic sandstone: very light gray (N 8); sandstone matrix same lithology as unit 8; clasts are black, pink and white quartzite pebbles up to 2 cm in diameter; trough crossbedded; forms a bench.	3.4
8	Conglomeratic sandstone: light greenish gray (5 G 8/1); coarse-very coarse grained; subangular-subrounded; moderately sorted; quartzose; trough crossbedded; noncalcareous; 60 m to NW this unit is totally scoured out by unit 9.	0.7
7	Siltstone: grayish yellow (5 Y 7/2); noncalcareous; thin secondary gypsum platelets.	0.7
6	Sandstone: light greenish gray (5 GY 8/1); very fine-medium	

	grained; subrounded; moderately sorted; quartzose; noncalcareous; trough crossbedded; forms a mottled ledge.	1.1
unconformity		
mottled strata:		
5	Sandy siltstone: mottled grayish purple (5 P 4/2) and pale greenish yellow (10 Y 8/2); this unit locally cut out by unit 6.	1.5
Cutler Formation:		
4	Sandy mudstone: pale reddish brown (10 R 5/4); noncalcareous.	0.8
3	Conglomeratic sandstone: pale olive (10 Y 6/2); fine-coarse grained; subangular; poorly sorted; quartzose; noncalcareous; clasts are pale olive (10 Y 6/2) and grayish red purple (5 RP 4/2) mudstone and siltstone up to 1 cm in diameter.	0.7
2	Sandstone: grayish red purple (5 RP 4/2) with pale greenish yellow (10 Y 8/2) mottles; very fine-fine grained; subrounded; moderately sorted; subarkosic; massive.	3.8
1	Sandstone: grayish red (10 R 4/2) with moderate yellowish green (5 GY 7/4) mottles; fine-coarse grained; subangular; poorly sorted; subarkosic; massive.	not measured

Type section of Poleo Formation

Measured in the NW¼ NW¼ sec. 36, T23N, R2E, Rio Arriba County. Strata dip 3–5° to N20°E.

unit	lithology	thickness (m)
Chinle Group:		
Petrified Forest Formation:		
12	Sandstone: pale olive (10 Y 6/2); very fine-fine grained; subangular and moderately sorted; micaceous litharenitic; very calcareous; trough crossbedded; caps ridges in this area.	1.7+
11	Conglomerate: pale yellowish brown (10 YR 6/2); siltstone and limestone (nodular calcrete) pebbles up to 7 mm in diameter; calcareous; trough crossbedded; contains bone fragments.	0.7
10	Mudstone: light brownish gray (5 YR 6/1); calcareous.	7.3
9	Muddy siltstone: dusky yellow (5 Y 6/4); calcareous.	2.4
Poleo Formation:		
8	Sandstone: dusky yellow (5 Y 6/4); very fine grained; subrounded and well sorted; micaceous subarkosic; noncalcareous; laminar and ripple laminar in shallow troughs; weathers flaggy.	1.7
7	Sandstone: same color and lithology as unit 6, but weathers flaggy.	1.2
6	Sandstone: dusky yellow (5 Y 6/4); very fine-fine grained; subrounded and moderately sorted; micaceous subarkosic; noncalcareous; lateral accretion crossbeds; liesegang bands.	2.7
5	Sandstone: grayish yellow (5 Y 8/4) and yellowish gray (5 Y 7/2); very fine grained; subangular-subrounded; well sorted; micaceous litharenitic; calcareous; lower 0.9 m are massive, upper 0.7 m trough crossbedded.	1.6
4	Silty mudstone and sandstone: mudstone is greenish gray (5 GY 6/1) and noncalcareous; sandstone is yellowish gray (5 Y 7/2) with dusky blue (5 PB 3/2) and dark yellowish orange (10 YR 6/6) mottles; very fine grained; subangular; well sorted; noncalcareous; micaceous litharenitic; black plant debris is up to 1 × 3 cm; unit is a trough bottom of low angle trough-crossbedded sandstone with mudstone and carbonaceous plant debris; base of unit is prominent scour.	0.5
3	Sandstone: yellowish gray (5 Y 7/2); very fine-fine grained; subrounded-subangular; moderately sorted; micaceous litharenitic; calcareous; trough crossbedded; trough bottoms are pebbly; forms a cliff.	2.6
unconformity		
Salitral Formation:		
2	Silty mudstone: grayish yellow green (5 GY 7/2); calcareous.	0.3–0.6
1	Silty mudstone: grayish red purple (5 RP 4/2); noncalcareous.	3.0+

Coyote Amphitheater

Measured in the NW¼ sec. 21, T23N, R3E. Strata dip 10° to N50°W.

unit	lithology	thickness (m)
San Rafael Group:		
Entrada Sandstone:		
16	Sandstone: pale reddish brown (10 R 5/4); very fine-fine grained; subrounded; moderately sorted; quartzarenitic; calcareous; trough crossbedded.	not measured
unconformity		
Chinle Group:		
Petrified Forest Formation:		
15	Mudstone, sandstone and sandy mudstone: mudstone is moderate reddish brown (10 R 4/6) with very pale green (10 G 8/8) reduction spots, noncalcareous, bentonitic, some cover; sandstone is pale green (5 G 7/2), very fine grained, subangular/subrounded, well sorted, micaceous litharenitic; sandy mudstone is moderate reddish orange (10 R 6/6) and pale reddish purple (5 RP 6/2); some gravelly scour-and-fill structures with bone fragments.	84.0
14	Siltstone: moderate reddish brown (10 R 4/6) with very pale green (10 G 8/2) reduction spots; contains some medium-coarse grained sandstone beds that fill scours and contain bone fragments.	42.0
13	Mudstone: same colors and lithology as unit 8.	8.0
12	Silty mudstone: same colors and lithology as unit 7.	26.5
11	Conglomeratic sandstone: same colors and lithology as unit 9; very persistent laterally.	0.8
10	Silty mudstone: same colors and lithology as unit 7.	16.8
9	Conglomeratic sandstone: pale reddish brown (10 R 5/4) and pale green (5 G 7/2); medium-very coarse grained; subrounded; poorly sorted; litharenitic; larger clasts are limestone (nodular calcrete); trough crossbeds.	1.0
8	Mudstone: pale reddish brown (10 R 5/4) with very pale green (10 G 8/2) streaks; contains numerous concretions of nodular calcrete; trough fill.	8.0
7	Silty mudstone: moderate reddish brown (10 R 4/6) with pale yellowish green (10 GY 7/2) reduction spots; very calcareous.	9.0
6	Muddy siltstone: moderate brown (5 YR 4/2) with pale green (5 G 7/2) mottles; very calcareous.	1.8
5	Siltstone and conglomerate: siltstone is moderate brown (5 YR 4/4), very calcareous and ripple laminar; conglomerate is brownish gray (5 YR 4/1) with clasts of mudstone and siltstone up to 1 cm in diameter; ledges of siltstone are intercalated with pebbly beds; NMMNHH locality 911, *Pseudopalatus* and *Typothorax*.	10.5
Poleo Formation:		
4	Sandstone with thin beds of mudstone: sandstone is light greenish gray (5 G 8/1), ripple laminar and same lithology as unit 2; mudstone is moderate brown (5 YR 4/4); units 4 and 5 represent a transitional interval between the Poleo and Petrified Forest Formations.	15.0
3	Sandstone: light greenish gray (5 G 8/1), weathers to grayish brown (5 YR 3/2); same lithology as sandstone in unit 2; noncalcareous; low angle crossbeds and ripple laminations; scour surfaces about 1.5 m apart; top 2 m very ripple laminar; forms cliff.	10.5
2	Sandstone: grayish yellow green (5 GY 7/2); very fine grained; subrounded; well sorted; micaceous litharenitic; noncalcareous; ripple laminar.	2.5
unconformity		
Salitral Formation:		
1	Mudstone and muddy sandstone: pale olive (10 Y 6/2); sandstone is very fine grained, subrounded-subangular, poorly sorted micaceous litharenitic; moderately calcareous; forms a slope above purple bentonitic mudstone.	3.5

Abiquiu Dam

Measured in the N½ sec. 8, T23N, R4E, Rio Arriba County.

unit	lithology	thickness (m)
	Chinle Group:	
	Petrified Forest Formation:	
34	Mudstone: grayish red purple (5 RP 4/2) and pale green (5 G 7/2); calcareous.	5.0
	Poleo Formation:	
33	Mudstone and interbedded sandstone: mudstone is same color and lithology as unit 22; sandstone is same color and lithology as unit 30.	3.8
32	Sandstone: same color and lithology as unit 30.	8.5
31	Siltstone: grayish red (10 R 4/2) and pale yellow green (10 GY 7/2); noncalcareous.	3.8
30	Sandstone: mottled grayish red (10 R 4/2) and moderate yellow green (5 GY 7/4); very fine grained; subrounded; well sorted; quartzose; ripples; planar bedding.	3.0
29	Siltstone: grayish red (10 R 4/2); slightly calcareous; platy; inclined heterolithic stratification.	1.1
28	Muddy siltstone: grayish red (10 R 4/2); noncalcareous; laterally is cut out by unit 29.	1.6
27	Sandstone: dusky yellow (5 Y 6/4); very fine grained; subangular; well sorted; quartzose; noncalcareous; planar crossbeds.	0.3
26	Sandstone: yellowish gray (5 Y 7/2); very fine grained; subangular; well sorted; quartzose; noncalcareous; massive.	2.0
25	Sandstone: pale olive (10 Y 6/2); very fine grained; subangular; well sorted; quartzose; very calcareous; planar and trough crossbeds; inclined heterolithic stratification.	14.2
24	Sandstone: grayish green (10 GY 5/2) and mottled dusky blue (5 PB 3/2); very fine grained; subrounded; well sorted; quartzose; very calcareous.	0.9
23	Sandstone: pale yellowish green (10 GY 7/2); very fine-fine grained; subrounded; poorly sorted; litharenitic; very calcareous; planar crossbeds; inclined heterolithic stratification.	3.2
22	Mudstone: pale red (10 R 6/2); calcareous.	6.0
21	Sandstone: grayish yellow green (5 GY 7/2); fine grained; subrounded; well sorted; hematitic quartzose; calcareous; planar crossbeds; inclined heterolithic stratification.	1.5
20	Mudstone: pale red (5 R 6/2); noncalcareous.	0.7
19	Sandstone and conglomerate: yellowish gray (5 Y 7/2); sandstone is very coarse, subrounded, poorly sorted, quartzose; clasts are black, red, gray quartzite up to 2 cm in diameter; planar bedded.	2.7
	unconformity	
	Salitral Formation:	
18	Mudstone: grayish yellow green (5 GY 7/2); noncalcareous.	1.0
17	Siltstone: moderate reddish brown (10 R 4/6); noncalcareous.	5.8
16	Sandstone: pale olive (10 Y 6/2); very fine grained; subrounded; well sorted; micaceous litharenitic; noncalcareous; ripple laminar.	0.2
15	Mudstone with floating sand grains: greenish gray (5 GY 6/1); pink and white sand grains up to 4 mm in diameter.	1.1
14	Mudstone: medium gray (N 5) with mottling of light greenish gray (5 G 8/1).	0.9
13	Sandstone: pale yellowish green (10 GY 7/2) and grayish orange (10 YR 7/2) and pale red purple (5 RP 6/2); very fine grained; subangular; moderately sorted; litharenitic.	1.0
12	Muddy sandstone: pale yellowish green (10 GY 7/2); very fine-medium grained; subrounded; poorly sorted; quartzose; noncalcareous.	1.3
11	Siltstone: very dusky red purple (5 RP 2/2) and very pale green (10 G 8/2); calcareous.	1.3
10	Silty mudstone: very dusky red purple (5 RP 2/2) and very pale green (10 G 8/2); noncalcareous; forms ledge.	6.0
9	Sandstone: lower 2.0 m is light bluish gray (5 B 7/1) and upper portion is pale greenish yellow (10 Y 8/2); fines up from medium-coarse grained at base to fine-medium grained; subrounded; moderately sorted; quartzose; noncalcareous.	5.7
8	Silty mudstone: pale red (5 R 6/2); noncalcareous.	5.5
	Agua Zarca Formation:	
7	Muddy sandstone: gray orange pink (5 YR 7/2); very fine grained; subrounded; well sorted; litharenitic; very calcareous; poorly developed low angle crossbeds.	3.0
6	Sandstone: very light gray (N 8); medium-coarse grained; subrounded; well sorted; quartzose; noncalcareous; horizontal lamination; unit thins laterally.	0.5
5	Conglomerate and sandstone: light gray (N 8); sandstone is fine-medium grained, subrounded, moderately sorted, quartzose; clasts are yellow, pink quartzite up to 6 cm in diameter.	1.5
4	Conglomerate and sandstone: light greenish gray (5 GY 8/1); sandstone is fine-medium grained, subrounded, moderately sorted, quartzose; clasts are yellow and pink quartzite up to 5 cm in diameter; unit thins laterally.	0.2
3	Sandstone: very light gray (N 8); very fine-fine grained; subrounded; well sorted; quartzose; noncalcareous.	0.3
2	Conglomeratic sandstone: grayish green (10 GY 5/2); very fine-coarse grained; subangular; poorly sorted; subarkosic; noncalcareous; clasts of quartzite up to 6 cm in diameter.	1.1
	unconformity	
	Cutler Formation:	
1	Sandy mudstone: grayish red (10 R 4/2) with reduction spots of pale green (5 G 7/2); noncalcareous.	2.9+

Canjilon quarry

Measured in the SW¼ sec. 2, T24N, R4E, Rio Arriba County.

unit	lithology	thickness (m)
	San Rafael Group:	
	Entrada Sandstone:	
29	Sandstone: pale greenish yellow (10 Y 8/2); very fine-fine grained; subrounded; moderately sorted; quartzarenitic; calcareous; trough crossbedded; forms a cliff.	not measured
	unconformity	
	Chinle Group:	
	Rock Point Formation:	
28	Muddy siltstone: grayish red (10 R 4/2) with pale yellowish green (10 GY 7/2) mottles; calcareous.	2.4
27	Siltstone: mottled pale red (5 R 6/2) and very pale green (10 G 8/2); very calcareous.	7.3
26	Siltstone: same colors and lithology as unit 25, except forms a slope.	4.5
25	Siltstone: moderate reddish brown (10 R 4/6) with very pale green (10 G 8/2) veinlets; very calcareous; ripple laminar ledges.	3.2
24	Silty mudstone and siltstone: mottled moderate red (5 R 5/4) and very pale green (10 G 8/2); very calcareous; bioturbated ledge (paleosol?).	2.5
23	Silty mudstone: pale reddish brown (10 R 5/4) and very pale green (10 G 8/2); very calcareous.	9.0
22	Silty mudstone: pale reddish brown (10 R 5/4); very calcareous; some thin sandstone ledges of unit 21 lithology with extensive bioturbation and ripple laminae.	7.5
21	Sandstone and sandy siltstone: sandstone is pale green (5 G 7/2), fine-medium grained, subangular, moderately sorted, clayey, quartzose and laminar; sandy siltstone is very pale green (10 G 8/2) and pale reddish brown (10 R 5/4), very calcareous.	2.0
20	Muddy siltstone with thin sandstone and conglomerate lenses: muddy siltstone is moderate reddish brown (10 R 4/6), slightly calcareous and has gypsiferous veins that are yellowish gray (5 Y 7/2); sandstone is moderate reddish orange (10 R 6/6), very fine grained, subrounded, well sorted, quartzarenitic; conglomerate is light olive gray (5 Y 5/2) and composed of very calcareous clasts of nodular calcrete.	18.5
19	Sandy mudstone: pale yellowish green (10 GY 7/2); slightly calcareous.	6.3
18	Mudstone intercalated with thin beds of ripple-laminar siltstone: mudstone is moderate reddish brown (10 R 4/6) and very calcareous; siltstone is very pale green (10 G 8/2), weathers moderate reddish brown (10 R 4/6) and is moderately calcareous.	13.0
	unconformity	
	Petrified Forest Formation:	
17	Mudstone: moderate reddish brown (10 R 4/6); very calcareous.	3.0

16	Muddy siltstone, siltstone and conglomerate: grayish yellow green (5 GY 7/2); very calcareous; same lithology and bedforms as unit 12.	5.0
15	Silty mudstone: same color and lithology as unit 13.	3.0
14	Muddy siltstone, siltstone and conglomerate: same colors and lithology as unit 12.	6.5
13	Silty mudstone: pale reddish brown (10 R 5/4); very calcareous.	4.0
12	Muddy siltstone, siltstone and conglomerate: muddy siltstone is grayish purple (5 P 4/2) and very calcareous; siltstone is pale olive (10 R 6/2), very calcareous and ripple laminar; conglomerate is light olive gray (5 Y 5/2), very calcareous and has same clast composition as unit 3 (clasts up to 1.5 cm in diameter); siltstone and conglomerate are interlaced with muddy siltstone in trough-form "arroyo-fill facies."	5.3
11	Muddy siltstone with interbeds of ripple-laminar siltstone: moderate reddish brown (10 R 4/6); very calcareous.	4.0
10	Conglomerate: pale red (10 R 6/2); same lithology as unit 3.	0.1
9	Mudstone: moderate reddish brown (10 R 4/6) with pale green (5 GY 7/2) mottles; noncalcareous.	8.3
8	Mudstone: grayish red purple (5 RP 4/2); noncalcareous.	1.7
7	Silty mudstone: grayish red (10 R 4/2); very calcareous.	6.0
6	Mudstone, siltstone and conglomerate: mudstone is greenish gray (5 G 8/1) and very calcareous; siltstone is light greenish gray (5 G 8/1) and very calcareous; conglomerate is greenish gray (5 G 6/1) and same lithology as unit 3; mudstone, siltstone and conglomerate form trough beds ("arroyo-fill facies"); calcareous concretions (nodular calcrete) are light greenish gray (5 G 8/1), and up to 5 cm in diameter.	1.5
5	Mudstone: moderate reddish brown (10 G 8/2) reduction spots; very calcareous; slightly sandy; nodular calcrete up to 3 cm in diameter.	2.5
4	Mudstone with thin beds of ripple-laminar siltstone: grayish red (10 R 4/2); very calcareous.	4.0
3	Conglomerate: very pale green (10 G 8/2); clasts are coarse-very coarse pebbles of limestone (calcrete); matrix is mudstone; very calcareous.	0.6
2	Mudstone: grayish red (10 R 4/2); moderately calcareous.	1.9
1	Muddy siltstone: pale reddish brown (10 R 5/4); calcareous.	4.5+

Rioarribasaurus quarry

Measured in the SW1/4 SE1/4 sec. 1, T24N, R4E, Rio Arriba County.

unit	lithology	thickness (m)
	San Rafael Group:	
	Entrada Sandstone:	
8	Sandstone: moderate reddish orange (10 R 6/6); very fine-fine grained; subrounded; well sorted; quartzarenitic; noncalcareous; trough crossbedded; forms a cliff.	not measured
	unconformity	
	Chinle Group:	
	Rock Point Formation:	
7	Covered.	5.5
6	Siltstone: grayish red (10 R 4/2) with very pale green (10 G 8/2) reduction spots; very calcareous; slope.	4.5
5	Siltstone: same colors and lithology as unit 2.	0.8
4	Siltstone: moderate reddish orange (10 R 6/6) with pale yellowish green (10 GY 7/2) reduction spots; very calcareous.	8.0
3	Sandstone: pale red (10 R 6/2); very fine grained; subrounded and well sorted; micaceous litharenitic; calcareous; trough crossbedded grading upward to laminar; forms a ledge.	3.8
2	Siltstone: moderate reddish orange (10 R 6/6) with very pale green (10 G 8/2) reduction spots; noncalcareous; laminar and ripple laminar with much horizontal bioturbation.	0.5–1.5
1	Silty mudstone: moderate reddish brown (10 R 4/6) with very pale green (10 G 8/2) reduction spots; very calcareous; some secondary gypsum in veins that cut across bedding; *Rioarribasaurus* quarry is 9.0 m above base of unit; correlates with unit 20 of Canjilon quarry section.	20.5

Minas de Pedro

Measured in the SE1/4 SW1/4 sec. 18 (unsurveyed), T24N, R6E, Rio Arriba County.

unit	lithology	thickness (m)
	Chinle Group:	
	Poleo Formation:	
15	Sandstone with conglomeratic beds: sandstone is light olive brown (5 Y 5/6), very fine grained, subangular-subrounded, moderately sorted, noncalcareous, micaceous litharenitic; conglomerate is light greenish gray (5 GY 8/1) and composed of siltstone and nodular calcrete clasts; laminar and planar crossbedded with conglomerate concentrated at scour bases.	11.3
14	Conglomerate: matrix is pale olive (10 Y 6/2), very fine-coarse grained, subangular quartzose sandstone; clasts are brown, white and red chert up to 1 cm in diameter; trough crossbedded.	1.6
13	Sandstone: yellowish gray (5 Y 7/2); very fine-fine grained; subrounded; moderately sorted; micaceous subarkosic; very calcareous; laminar.	2.2
12	Sandstone: yellowish gray (5 Y 7/2); very fine-fine grained; subangular-subrounded; moderately sorted; micaceous quartzarenitic; very calcareous; trough crossbedded; multistoried with pebbly beds at scour bases.	10.3
11	Sandstone: pale greenish yellow (10 Y 8/2), weathers moderate yellowish brown (10 Y 5/4); fine grained; subrounded; well sorted; quartzarenitic; noncalcareous; trough crossbedded.	2.0
10	Sandstone: grayish orange (10 YR 7/4); very fine grained; subrounded; well sorted; arkosic litharenite; calcareous; some cover.	1.3
9	Conglomeratic sandstone: sandstone is dusky yellow (5 Y 6/4), very fine-fine grained, subangular, moderately sorted, micaceous litharenitic, calcareous; pebbles are light gray, black, white quartzite and petrified wood; trough crossbedded; scour base with 0.3–0.6 m of relief.	3.0
	unconformity	
	Salitral Formation:	
8	Sandy mudstone and muddy sandstone: sandy mudstone is mottled grayish red purple (5 RP 4/2) and yellowish gray (5 Y 7/2), bentonitic and very calcareous; muddy sandstone is medium light gray (N 6), fine grained, subangular, poorly sorted, lithic wacke; trough crossbedded ledges with mudstone partings.	5.5
	Agua Zarca Formation:	
7	Sandstone: pale greenish yellow (10 Y 8/2); fine-medium grained; subrounded; moderately sorted; quartzose; slightly calcareous; trough crossbedded; some siliceous pebbles.	3.0
6	Sandstone: yellowish gray (5 Y 7/2); very fine-medium grained; subrounded; poorly sorted; feldspathic litharenitic; noncalcareous; trough crossbedded; contains some siliceous pebbles; upper half of unit thinner bedded with some mudstone partings.	3.1
5	Sandy mudstone: pale reddish purple (5 RP 6/2); noncalcareous.	1.5
4	Sandstone: yellowish gray (5 Y 7/2); fine-medium grained; subrounded; moderately sorted; micaceous feldspathic litharenitic; calcareous; trough crossbedded; some dispersed siliceous pebbles.	2.8
3	Conglomerate: matrix is pale green (5 G 7/2), fine-medium grained, subangular, poorly sorted quartzose sandstone; clasts are greenish black (5 G 2/1) chert and white quartzite up to 15 cm in diameter; trough crossbedded.	0.5
	unconformity	
	mottled strata:	
2	Siltstone: mottled grayish yellow green (5 GY 7/2) and dark reddish brown (10 R 3/4); bioturbated and massive.	1.2–1.4
	Cutler Formation:	
1	Sandstone: moderate reddish brown (10 R 4/6); very fine-fine grained; subangular; moderately sorted; micaceous lithic wacke; noncalcareous; trough crossbedded.	2.0+