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TRIASSIC STRATIGRAPHY IN THE SANGRE DE CRISTO MOUNTAINS, NEW MEXICO

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Abstract—Triassic strata exposed in the Sangre de Cristo Mountains of Colfax, Taos, Mora and San Miguel Counties, New Mexico, pertain to eight formations: Moenkopi, Santa Rosa, Baldy Hill, Garita Creek, Trujillo, Bull Canyon, Redonda and Johnson Gap. The Middle Triassic Anton Chico Member of the Moenkopi Formation disconformably overlies the Permian Bernal or Glorieta Formations from Montezuma Gap to Rayado Creek and is as much as 47.0 m thick and dominated by grayish-red, trough-crossbedded litharenite and lithic wacke. We apply the informal term mottled strata to the paleosol(s) developed in the top of the Moenkopi and the Pennsylvanian-Permian Sangre de Cristo Formation. The Upper Triassic Santa Rosa Formation disconformably overlies the Moenkopi Formation or, north of Rayado Creek, the Pennsylvanian-Permian Sangre de Cristo Formation. The Santa Rosa is as much as 38.5 m thick and is dominated by yellowish gray, trough-crossbedded quartzarenite. South of La Cueva three members of the Santa Rosa Formation (Tecolotito, Los Esteros and Tres Lagunas) are present, but to the north only the Tecolotito Member is present. The Baldy Hill Formation is 13.0 m of mottled siltstone at Ricardo Creek that overlies the Santa Rosa Formation. To the south, as much as 26.0 m of dominantly red mudstone of the Garita Creek Formation overlie the Santa Rosa Formation. The Trujillo Formation disconformably overlies the Baldy Hill and Garita Creek Formations and is the most pervasive Triassic stratigraphic unit in the Sangre de Cristo Mountains. It is as much as 58.0 m thick and is dominated by olive, yellow, and/or gray trough-crossbedded and laminar quartzose sandstone and limestone- and siltstone-pebble conglomerate. Reddish, bentonitic mudstones of the Bull Canyon Formation overlie the Trujillo Formation at Naranjos and to the south. The Redonda Formation (= Naranjos Formation), 60–65 m thick and dominated by reddish siltstone, disconformably overlies the Bull Canyon Formation in this area. North of Naranjos, we assign the post-Trujillo Triassic strata to the Johnson Gap Formation. We thus redefine the Johnson Gap Formation by eliminating the Trujillo-equivalent strata from its type section and recognize it as 15.4–84.9 m of variegated siltstone, litharenite and intraformational conglomerate that crops out from Rayado Creek, New Mexico to Stonewall, Colorado. The Entrada Sandstone disconformably overlies the Johnson Gap and Redonda Formations in the Sangre de Cristo Mountains.

INTRODUCTION

Triassic sedimentary rocks are exposed in the southern Sangre de Cristo Mountains along a discontinuous belt that extends from Ricardo Creek near the New Mexico–Colorado line to Romeroville at the southern end of the range (Fig. 1). These exposures are generally steeply dipping hogbacks and associated strike valleys that are covered by soil and vegetation. It is not surprising that little effort has been made to study these Triassic strata, and their stratigraphy is poorly understood. Here, we present a detailed study of the Triassic strata of the southern Sangre de Cristo Mountains and correlate these strata with better known Triassic sediments exposed on the Southern High Plains to the east.

PREVIOUS STUDIES

Hayden (1869) was the first trained geologist to examine Triassic strata in the Sangre de Cristo Mountains, although he did not recognize them as Triassic. Near Mora, Hayden (1869, p. 59) noted an "upper series" of "red sandstones" that encompass what are now known to be Triassic strata. And, in Gallinas Canyon, near "Las Vegas Hot Spring," he (p. 63) described the entire stratigraphic section including the Triassic strata we describe here in our Montezuma Gap section.

Stevenson (1881) first recognized Triassic strata in the Sangre de Cristo Mountains of New Mexico. He briefly described red beds of the "Jura-Trias" as far north as Coyote Creek near Guadalupita (Mora County). However, Stevenson's "Jura-Trias" must have included some Permian red beds, and his identification of some of the red beds as Triassic was based on lithology and stratigraphic position.

Darton (1910, fig. 17), in a cross section from Costilla Pass to Sierra Grande and beyond, depicted vertical red beds above the Magdalena Group near Costilla Pass that he described as "Permian and Triassic." Darton (1915, sheet 11) also identified "Red Beds" of "Triassic? and Carboniferous" age in the Turkey Mountains, southeast of Ocate.

Case (1914, fig. 11, pp. 256–258) illustrated and described the red beds at Montezuma Gap near Las Vegas as "vertical beds of Triassic age on the south side of the valley at Las Vegas Hot Springs" (p. 258). He stated that he found "a Phytosaur or Dinosaur tooth" in a bed of conglomerate near the middle of these red beds that demonstrated their Triassic age. Case (1915, pl. 12, fig. 3, p. 61) repeated these observations and concluded that a narrow belt of Triassic red beds crops out along the front range of the Sangre de Cristo Mountains from Montezuma Gap north to the Colorado–New Mexico border (Case, 1915, pl. 1).

Darton (1928b), however, in his geological map of New Mexico, extended the front range outcrops of the Triassic (as Dockum Group including the Santa Rosa Sandstone) to just north of Guadalupita. Darton (1928a, pp. 267–274) discussed red beds of the "Dockum Group" from Romeroville to the Turkey Mountains, but clearly made an error in this discussion by assigning strata of the Santa Rosa Formation to the Permian "Chupadera Formation."

Ray and Smith (1941) recognized no Triassic strata in the Moreno Valley, but Smith and Ray (1943, p. 899) suggested that red beds of the Dockum Group probably are present in the adjacent Cimarron Range. Northrop et al. (1946) established the Triassic nomenclature used by almost all subsequent workers in San Miguel and Mora Counties. Thus, above the Santa Rosa Sandstone, they recognized the Chinle Formation with three informal members: lower shale, middle sandstone and upper shale. Northrop et al. (1946) included the Santa Rosa and Chinle Formations in the Dockum Group.

Griggs and Hendrickson (1951) followed the stratigraphic nomenclature of Northrop et al. (1946), as did Bachman (1953). However, Bachman (1953) named the Naranjo Formation for the youngest Triassic strata near Ocate. Baltz and Bachman (1956) provided a state-of-the-art review of the Triassic stratigraphy in the southern Sangre de Cristo Mountains. According to them, Triassic strata in this region pertained to the Dockum Group consisting of three formations (in ascending order): Santa Rosa, Chinle (in some places divisible into the three, informal members delineated by Northrop et al., 1946) and Naranjo. This nomenclature has been essentially used by all subsequent workers (Hayes, 1957; Robinson et al., 1964; Baltz, 1965; Simms, 1965; Clark and Read, 1972; Goodknight, 1973; Lessard and Bejnar, 1976; Baltz and O'Neill, 1984, 1986; De Luca, 1986; De Luca and Eriksson, 1989).

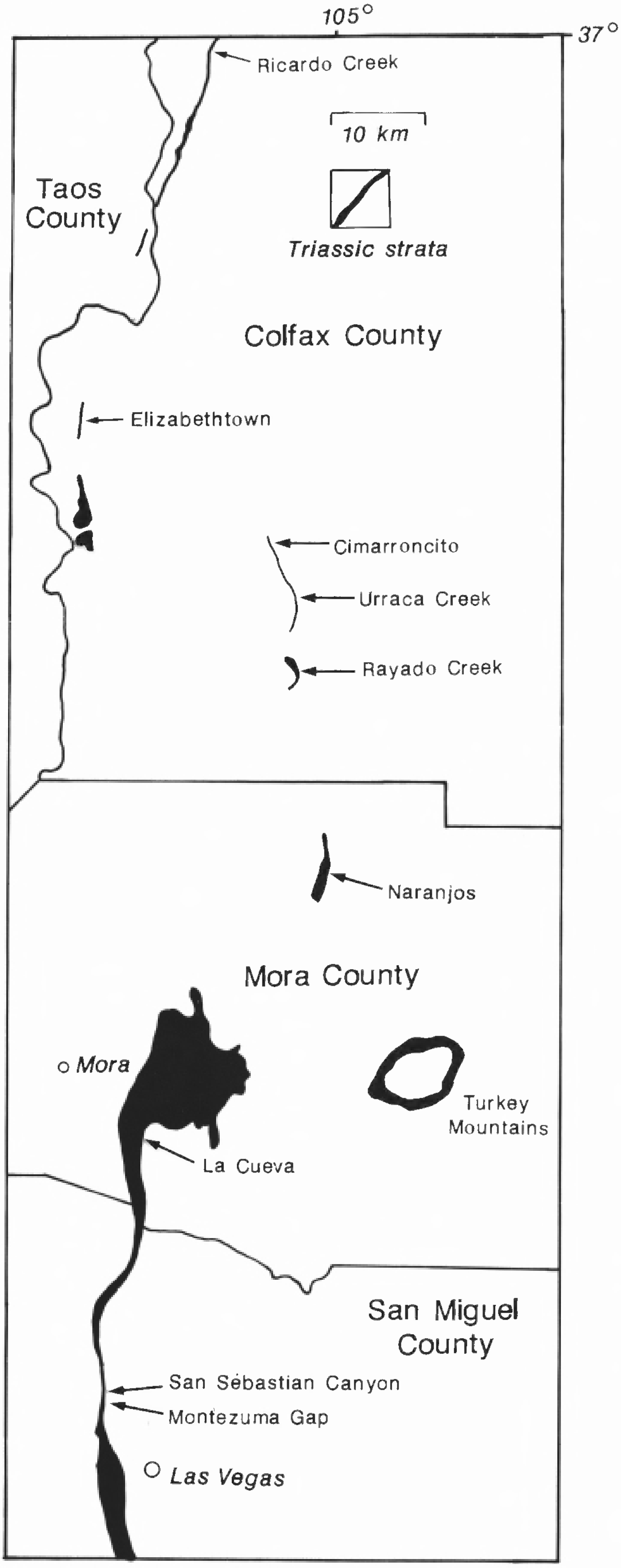


FIGURE 1. Distribution of Triassic strata in the Sangre de Cristo Mountains of New Mexico (after Dane and Bachman, 1965) and location of measured sections described here (Fig. 2). The Johnson Gap section (Fig. 2) is located in south-central Colorado just north of the Ricardo Creek section.

Johnson and Baltz (1960; also see Baltz, 1965; Johnson, 1969) named the Johnson Gap Formation for Triassic strata in the Sangre de Cristo Mountains of southern Colorado. They extended the distribution of the Johnson Gap Formation into northern Colfax County, New Mexico (also see Pillmore, 1976). Recently, Lucas et al. (1985) suggested abandoning Bachman's (1953) name Naranjo Formation in favor of the Tucumcari basin name Redonda Formation. Here, we adopt this suggestion and argue that most of the Triassic strata in the southern Sangre de Cristo Mountains pertain to rock-stratigraphic units recognized in the Tucumcari basin.

MOENKOPI FORMATION

Strata of the Anton Chico Member of the Moenkopi Formation (Lucas and Hunt, 1987, 1989) crop out in the Sangre de Cristo Mountains as far north as Rayado Creek (Figs. 1, 2). These strata are dominated by grayish-red, trough-crossbedded litharenites and lithic wackes with lesser amounts of mudstone and siltstone (Figs. 2, 3A, 5A). They range in thickness from 27.9 m at Montezuma Gap to as much as 47.9 m at La Cueva (Fig. 2; Appendix).

Moenkopi strata are the oldest Triassic rocks in the Sangre de Cristo Mountains. They rest disconformably on Permian rocks of the Bernal and Glorieta Formations (Figs. 2, 4F). The Upper Triassic Santa Rosa Formation disconformably overlies the Moenkopi Formation in the Sangre de Cristo Mountains as far north as Rayado Creek. To the north of this locale, the Santa Rosa rests directly on Lower Permian (Wolfcampian) rocks of the Sangre de Cristo Formation.

Strata we identify as Moenkopi in the Sangre de Cristo Mountains have generally been identified by previous workers (e.g., Bachman, 1953; Baltz, 1965; Baltz and O'Neill, 1984, 1986) as Permian Bernal Formation. However, the Bernal is easily distinguished from the Moenkopi Formation using lithologic criteria. Thus, the Bernal Formation is dominated by massive (intensively bioturbated) reddish-brown and reddish-orange, very fine-grained sandy siltstone and mature, gypsiferous sandstone. This contrasts with Moenkopi strata that are dominated by grayish-red and grayish-orange siltstone and immature, trough-crossbedded sandstone (lithic wackes and litharenites) intercalated with some intraformational conglomerates (cf. Lucas and Hayden, 1989a, b).

Strata of the Bernal Formation underlie the Moenkopi Formation at Montezuma Gap. This is the northernmost outcrop of the Bernal known to us. At La Cueva and Rayado Creek, the Moenkopi rests directly on the Glorieta Sandstone (Figs. 2, 4F). Thus, strata mapped as Bernal Formation (Baltz and O'Neill, 1984) or clastic member of the San Andres Formation (Northrop et al., 1946) north of Montezuma Gap pertain to the Moenkopi Formation. Near Naranjos, Bachman (1953) reported 38.4 m of "brownish red siltstone and fine-grained sandstone" that he mapped as Bernal Formation. However, we have examined these strata and they consist of two lithologies typical of the Moenkopi Formation (cf. Lucas and Hunt, 1987): (1) grayish-red purple (5 RP 4/2), very fine-grained, subangular, well sorted, non-calcareous, micaceous litharenite that is trough crossbedded (Fig. 5A); and (2) grayish-red purple (5 RP 4/2), medium-coarse-grained, subrounded, poorly sorted, non-calcareous, trough-crossbedded litharenite. Thus, we conclude that the Moenkopi Formation, not the Bernal Formation, rests directly on the Glorieta Sandstone near Naranjos.

The Anton Chico Member of the Moenkopi Formation is widespread in New Mexico. It extends from Rayado Creek on the north southward to Carthage in Socorro County (Hunt and Lucas, 1987; Hayden and Lucas, 1988). And, from Upper Nutria, McKinley County to the west it extends eastward to Alamogordo Reservoir in De Baca County (Hayden and Lucas, 1988; Lucas and Hayden, 1989b). Fossil vertebrates, ostracodes and charophytes indicate the Anton Chico Member of the Moenkopi Formation is of Middle Triassic (Anisian) age (Lucas and Hunt, 1987, 1989; Lucas and Hayden, 1989b).

MOTTLED STRATA

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

Here, however, we use the term "mottled strata" as an informal unit. It is not included in any formation, although these strata are assigned to the Chinle Formation on the Colorado Plateau (Stewart et al., 1972). The pedogenically altered rocks in the Sangre de Cristo Mountains are either at the top of the Moenkopi Formation (at Montezuma Gap and Naranjos) or the top of the Pennsylvania-Permian Sangre de Cristo Formation (at Ricardo Creek) (Fig. 2). Mottled strata in the Sangre de Cristo Mountains range in thickness from 0.4 to 4.0 m and are yellow, green, purple and red mottled sandstone and conglomerate. For example, at Naranjos, the mottled strata at the top of the Moenkopi Formation are very dusky red-purple (5 RP 2/2) and moderate yellowish-green (5 GY 7/4), quartzose, subrounded-very angular, medium-grained sandstone. Where the mottled strata are not present in the Sangre de Cristo Mountains, we assume they were removed at the onset of deposition of the Santa Rosa Formation.

SANTA ROSA FORMATION

As is the case in the Tucumcari basin of east-central New Mexico (Lucas and Hunt, 1989), the oldest Upper Triassic strata in the Sangre de Cristo Mountains pertain to the Santa Rosa Formation. Indeed, the three members of the Santa Rosa Formation defined by Lucas and Hunt (1987) in east-central New Mexico can be recognized as far north as La Cueva (Fig. 2).

The basal, Tecolotito Member of the Santa Rosa Formation ranges in thickness from 5.2 m at Montezuma Gap to 21.7 m at La Cueva. The Tecolotito Member is dominated by yellowish-gray and olive-gray, trough-crossbedded quartzarenite and extraformational silica-pebble conglomerate (Figs. 2, 3A–B, 4A). At Montezuma Gap and La Cueva it is overlain by 6.4–13.5 m of variegated mudstone and silcrete of the Los Esteros Member of the Santa Rosa Formation. The uppermost, Tres Lagunas Member of the Santa Rosa Formation disconformably overlies these mudstone-dominated strata at Montezuma Gap and La Cueva. The Tres Lagunas Member is 8.0 m of mostly yellowish-gray, trough-crossbedded quartzarenite.

North of La Cueva, we are unable to differentiate the three members of the Santa Rosa Formation. Instead, the Santa Rosa Formation from Rayado Creek to Ricardo Creek is 3.5–38.5 m of sandstone and conglomerate. The evident thickening of the Tecolotito Member from Montezuma Gap to La Cueva, the relative thinning of the Los Esteros and Tres Lagunas Members on this transect and the silica-pebble conglomerate in the Santa Rosa at Urraca Creek lead us to suggest that the Santa Rosa Formation north of La Cueva is represented only by a northward extension of the Tecolotito Member. The Los Esteros and Tres Lagunas Members have apparently pinched out.

Most previous workers have used the term Santa Rosa Formation for some of the Upper Triassic strata in the Sangre de Cristo Mountains, though not all use it in the same way we do. Thus, Northrop et al.'s (1946) Santa Rosa Sandstone is the same as our Santa Rosa Formation. However, Baltz and O'Neill's (1984, 1986) Santa Rosa Sandstone includes the Santa Rosa, Garita Creek and Trujillo Formations of our usage. Bachman's (1953) "Santa Rosa Sandstone" is 129 m of mudstone-dominated section near Ocate. A sample of this mudstone is grayish yellow-green (5 GY 7/2) and grayish red-purple (5 RP 4/2), not calcareous and bentonitic. We do not believe these strata pertain to the Santa Rosa but instead belong to the Garita Creek Formation. The Santa Rosa apparently is not exposed near Ocate due to faulting. The lower, sandstone-dominated portion of Clark and Read's (1972) Dockum Group in the Eagle Nest area of Taos County is the Santa Rosa Formation of our usage. Thus, near Elizabethtown, the Santa Rosa Formation (units 1–4 of the "Dockum Group" of Clark and Read, 1972, p. 141) is yellowish-gray (5 Y 8/1) and moderate greenish-yellow (10 Y 7/4), fine- to coarse-grained, subrounded quartzarenite above mottled strata developed in the top of the Sangre de Cristo Formation. Pillmore's (1976) "lower unit" at Ricardo Creek includes strata we term mottled strata and Santa Rosa Formation.

BALDY HILL FORMATION

We assign 13.0 m of mottled and massive-to-bioturbated siltstone in the Ricardo Creek section (Fig. 2) to the Baldy Hill Formation. These strata overlie the Santa Rosa Formation and are disconformably overlain by the Trujillo Formation. They thus occupy the same stratigraphic position and are lithologically very similar to the type Baldy Hill Formation in the Dry Cimarron Valley of Union County (Baldwin and Muehlberger, 1959; Lucas et al., 1987). In the Dry Cimarron Valley, the Baldy Hill overlies the Santa Rosa Formation and is disconformably overlain by the Cobert Canyon Sandstone Bed, a correlative of the Trujillo Formation (Lucas et al., 1987). At its type locality, the Baldy Hill Formation is at least 37 m of mottled, massive to bioturbated sandstone and siltstone. It is strikingly similar to the strata we identify as Baldy Hill at Ricardo Creek.

Our identification of the Baldy Hill Formation at Ricardo Creek extends this unit's outcrops 150 km to the west of the Dry Cimarron Valley. In effect, we argue that it and other Triassic strata are continuous beneath the Upper Cretaceous cover of the Raton basin that intervenes between Ricardo Creek and Union County (also see Roberts et al., 1976). We also considered the possibility that strata we term the Baldy Hill at Ricardo Creek should be assigned to the Los Esteros Member of the Santa Rosa Formation or to the Garita Creek Formation. However, stratigraphic position, lithology, geographic proximity and stratigraphic relationships of the Santa Rosa and Garita Creek Formations suggest assignment of the Ricardo Creek strata to the Baldy Hill Formation as the most reasonable, albeit tentative, conclusion.

GARITA CREEK FORMATION

We assign the mudstone-dominated section between the Santa Rosa and Trujillo Formations from Montezuma Gap to Urraca Creek to the Garita Creek Formation. Mudstones of the Garita Creek Formation along this transect typically are grayish-red, purple, reddish-brown and bentonitic (Fig. 3C, 4B, 5D). The unit ranges in thickness from 7.8–26.0 m. It often underlies a strike valley covered with soil and vegetation.

Lucas and Hunt (1989) defined the Garita Creek Formation in the Tucumcari basin of east-central New Mexico. Extension of the Garita Creek Formation along the Sangre de Cristo front range is easily undertaken on the basis of lithology and stratigraphic position. In the Tucumcari basin, the Garita Creek Formation contains a late Carnian (Late Triassic) vertebrate fauna (Hunt et al., 1989).

TRUJILLO FORMATION

The most pervasive and easily recognized Triassic stratigraphic unit in the Sangre de Cristo Mountains is the Trujillo Formation. From Montezuma Gap to Ricardo Creek it is present across the front range and varies in thickness from 11.9 m to 58.0 m. The Trujillo is characterized by olive, yellow and/or gray, trough-crossbedded or laminar, quartzose sandstone and limestone- and/or siltstone-pebble conglomerate (Fig. 3D–E). The Trujillo Formation forms a prominent hogback at all its outcrops in the Sangre de Cristo Mountains (Figs. 3C–D, 4C, 5D) and is readily distinguished from the underlying Garita Creek Formation and overlying Bull Canyon Formation, both being red mudstone-dominated units. The Trujillo Formation ranges in thickness from 11.9 m (Richardo Creek) to 58.0 m (San Sebastian Canyon) and thus generally thickens southward.

Our Trujillo Formation is the same unit Northrop et al. (1964) mapped as the middle sandstone member of the Chinle Formation. The upper part of the Santa Rosa Formation of Baltz and O'Neill (1984) is our Trujillo Formation. Near Naranjos, the Trujillo Formation is the sandy interval at the top of Bachman's (1953) "Santa Rosa Sandstone." These Trujillo sandstones are grayish yellow-green (5 GY 7/2), fine-medium grained, subrounded-subangular, well sorted, trough-crossbedded quartzarenites. They contain basal scour-filling conglomerates that are

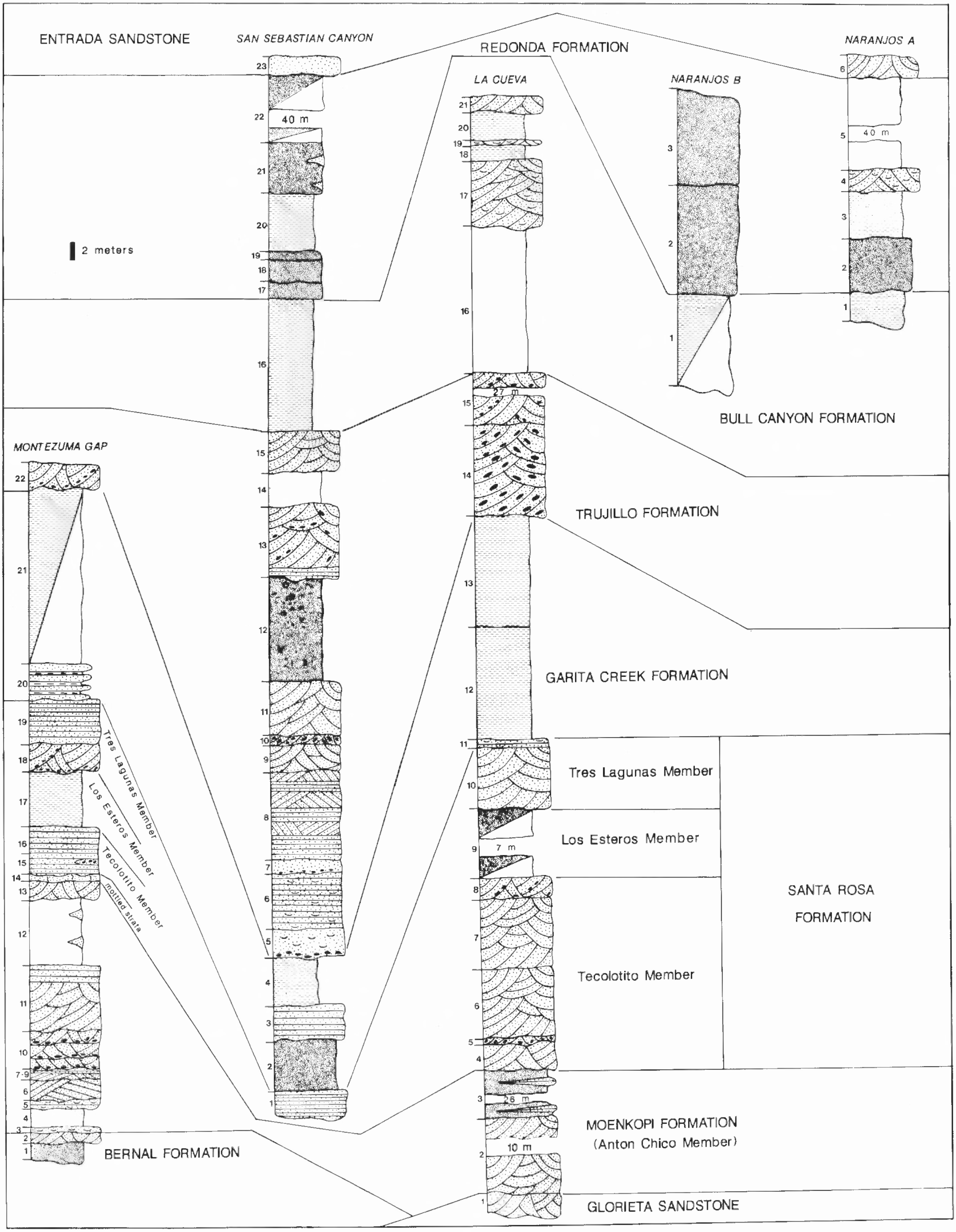
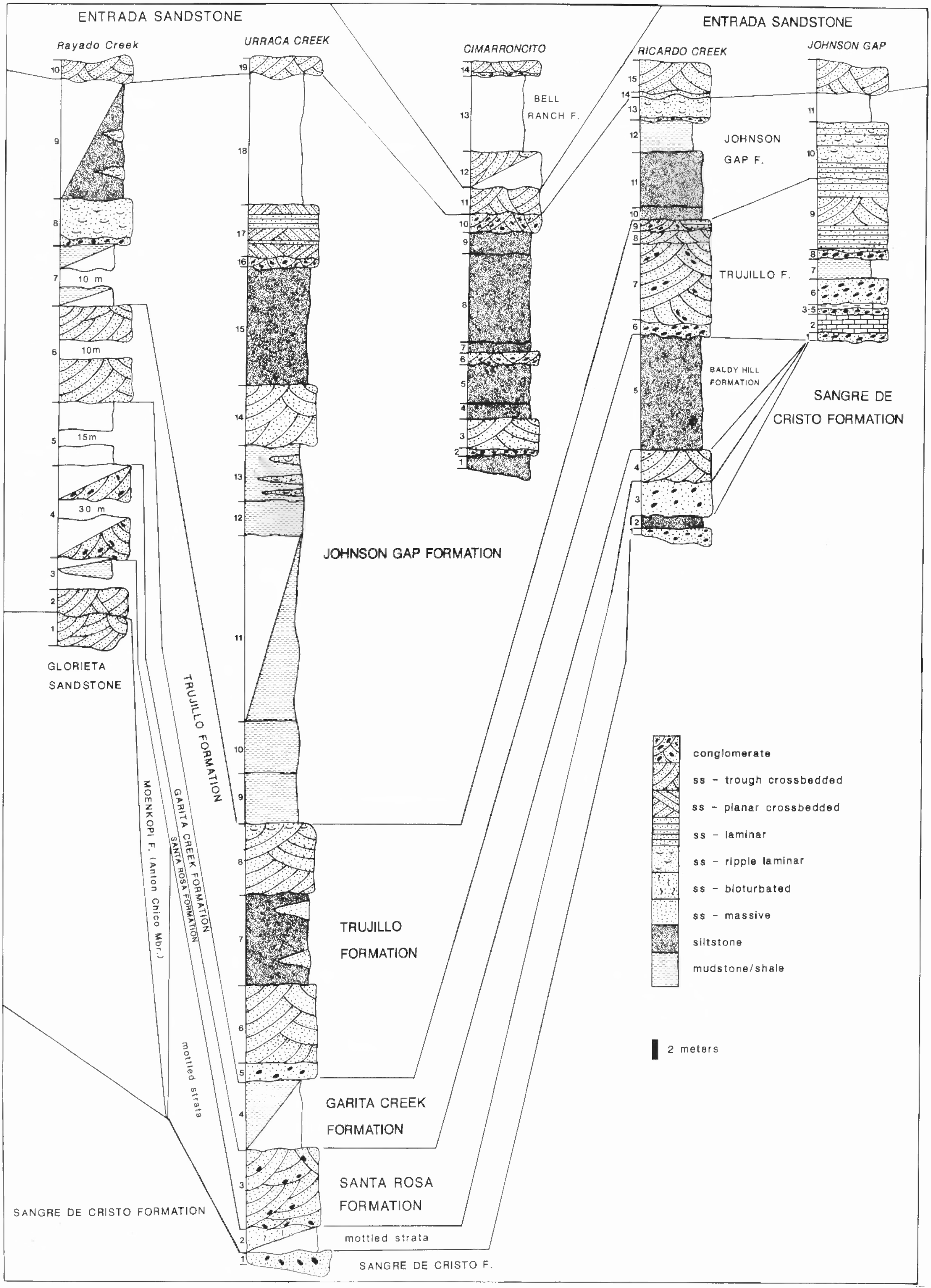


FIGURE 2. Measured stratigraphic sections of Triassic strata in the Sangre de Cristo Mountains. See Appendix for description of lithologic units in measured sections.


ENTRADA SANDSTONE
Rayado Creek
URRACA CREEK
CIMARRONCITO
RICARDO CREEK
JOHNSON GAP
ENTRADA SANDSTONE
BELL RANCH F.
JOHNSON GAP F.
TRUJILLO F.
BALDY HILL FORMATION
SANGRE DE CRISTO FORMATION
10 m
10m
15m
30 m
GLORIETA SANDSTONE
JOHNSON GAP FORMATION
TRUJILLO FORMATION
GARITA CREEK FORMATION
SANTA ROSA FORMATION
MOENKOPI F. (Anton Chico Mbr.)
mottled strata
TRUJILLO FORMATION
GARITA CREEK FORMATION
SANTA ROSA FORMATION
mottled strata
SANGRE DE CRISTO FORMATION
SANGRE DE CRISTO F.
conglomerate
ss - trough crossbedded
ss - planar crossbedded
ss - laminar
ss - ripple laminar
ss - bioturbated
ss - massive
siltstone
mudstone/shale
2 meters

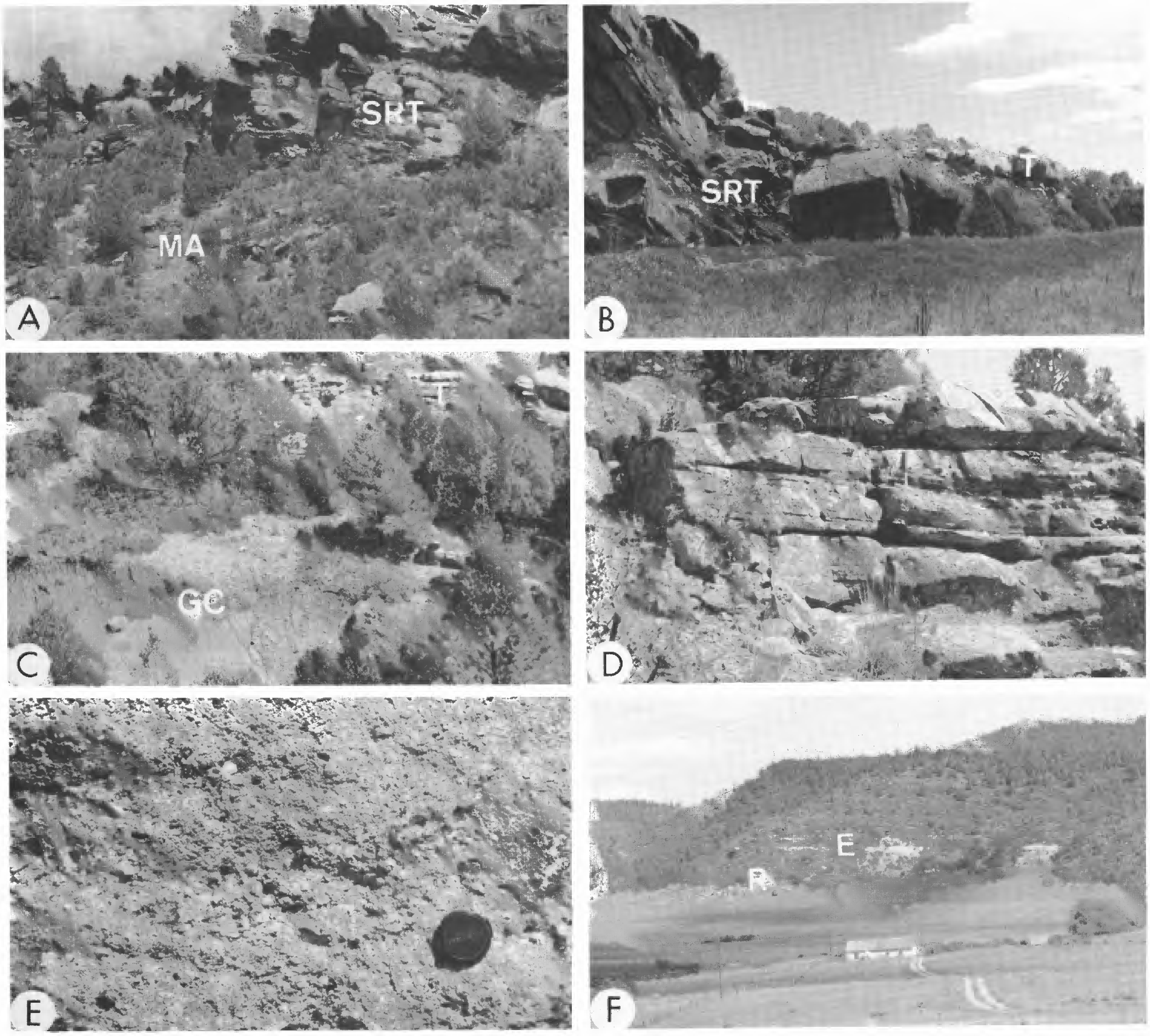


FIGURE 3. Triassic strata of the La Cueva section. A, Anton Chico Member of Moenkopi Formation (MA) overlain by Tecolotito Member of Santa Rosa Formation (SRT). B, Tecolotito Member of Santa Rosa Formation (SRT) and hogback formed by Trujillo Formation (T). C, Garita Creek Formation (GC) overlain by Trujillo Formation (T). D, Close-up of trough-crossbedded conglomerate and sandstone of Trujillo Formation. E, Close-up of characteristic intraformational conglomerate of Trujillo Formation. F, Jurassic Entrada Sandstone (E) above Triassic Redonda Formation (R) across the valley to east of La Cueva section.

pale olive (10 Y 6/2) siltstone- and limestone-pebble dominated. They thus are typical, intraformational conglomerates in contrast to Santa Rosa Formation conglomerates which typically are extraformational, silica-pebble conglomerates. Most of Pillmore's (1976) "middle unit" of the Chinle Formation at Ricardo Creek is our Trujillo Formation. Indeed, most of the Johnson Gap Formation, as originally defined by Johnson and Baltz (1960), is Trujillo Formation of our usage (see below).

BULL CANYON FORMATION

We recognize the Bull Canyon Formation as far north as Naranjos. To the south it is 14.9 to at least 29.6 m of mostly reddish brown and grayish red, bentonitic mudstone. The Bull Canyon Formation overlies the Trujillo Formation and is disconformably overlain by the Redonda Formation.

North of Naranjos the presence of the Bull Canyon Formation cannot be established. It might be represented by mudstones at or near the base of the unit we term the Johnson Gap Formation. However, north of Naranjos, it seems more likely that the Bull Canyon Formation has pinched out or been eroded away prior to deposition of the Johnson Gap Formation.

At Naranjos, Bachman (1953) indicated a thickness of 195 m for a mudstone-dominated "Chinle Formation." These strata include or are equivalent totally to the Bull Canyon Formation of our usage. However, we question Bachman's (1953) estimated thickness of these strata. Dip changes and extensive cover of these rocks on the north side of Ocate Creek (Fig. 5B), where Bachman must have estimated their thickness, suggest structural complexity that is impossible to evaluate. Therefore, we conclude that the thickness of the Bull Canyon Formation near Naranjos is uncertain.

In the La Cueva area, our Bull Canyon Formation is the unit Baltz and O'Neill (1984) termed the lower member of the Chinle Formation

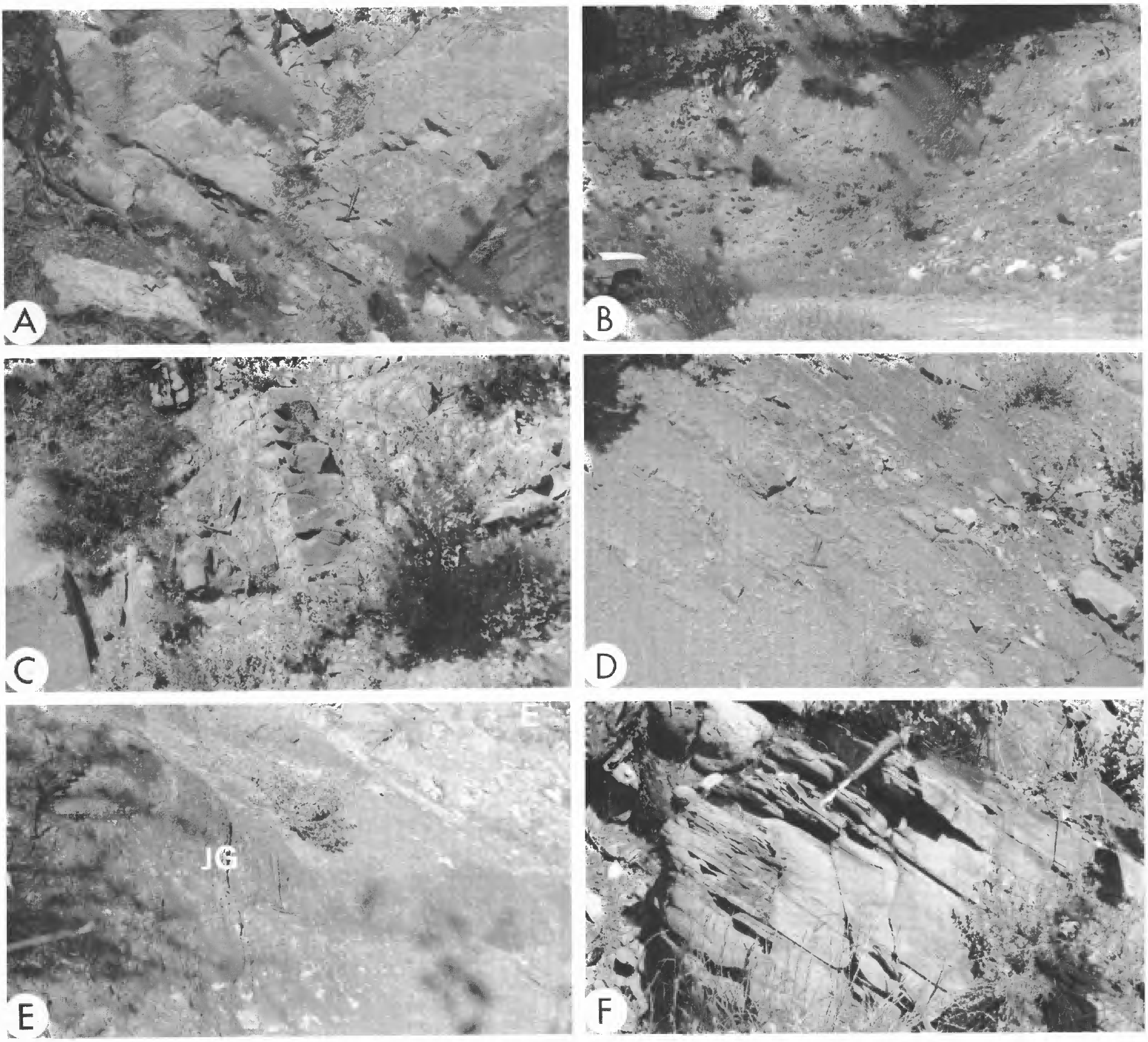


FIGURE 4. Triassic and Permian strata on the Philmont Scout Ranch. A, Basal conglomerate and sandstone of the Tecolotito Member of the Santa Rosa Formation at the Urraca Creek section. B, Mudstone of Garita Creek Formation at the Urraca Creek section. C, Trujillo Formation at the Urraca Creek section. D, Siltstones and sandstones of the Johnson Gap Formation at the Cimarroncito section. E, Pedogenically modified siltstones of the upper part of the Johnson Gap Formation (JG) and the overlying Jurassic Entrada Sandstone (E), Cimarroncito section. F, Permian Glorieta Sandstone at Rayado Creek section.

(Fig. 3F). They estimate the thickness of the Bull Canyon Formation near La Cueva as 140 m.

Lucas and Hunt (1989) coined the name Bull Canyon Formation for Upper Triassic strata in Bull Canyon, Guadalupe County. In the Tucumcari basin, the Bull Canyon Formation produces a diverse vertebrate fauna of early Norian age (Hunt and Lucas, 1989; Lucas and Hunt, 1989).

REDONDA FORMATION

Like the Bull Canyon Formation, we recognize the Redonda Formation as far north as Naranjos. From San Sebastian Canyon to Naranjos, the Redonda maintains uniform thickness of 60–65 m. It is dominated by reddish brown and grayish red siltstone (Figs. 4D, 5B–C). Some horizons contain carbonate nodules, extensive mottling, poor sorting and a lack of sedimentary structures (Fig. 4E) that indicate they are nodular calcareous paleosols (cf. Blodgett, 1988). Lithological resemblance to the Redonda Formation in the Tucumcari basin (Lucas et al., 1985; Hester, 1988; Lucas and Hunt, 1989) is so striking that we feel no hesitation in assigning the strata between the Bull Canyon and the Entrada Formations at San Sebastian and Naranjos to the Redonda Formation. This supports Lucas et al. (1985, p. 175) who argued that the term Naranjos Formation of Bachman (1953) should be abandoned in favor of Redonda Formation.

The Redonda Formation is the youngest Triassic stratigraphic unit in the Tucumcari basin of east-central New Mexico. It contains an extensive vertebrate fauna of middle(?) Norian age (Hunt and Lucas, 1989; Lucas and Hunt, 1989; Hunt, 1990).

JOHNSON GAP FORMATION

We apply the term Johnson Gap Formation to all post-Trujillo Triassic strata north of Naranjos. The Johnson Gap Formation in the Sangre de Cristo Mountains of New Mexico is thus 15.4–84.9 m thick and is

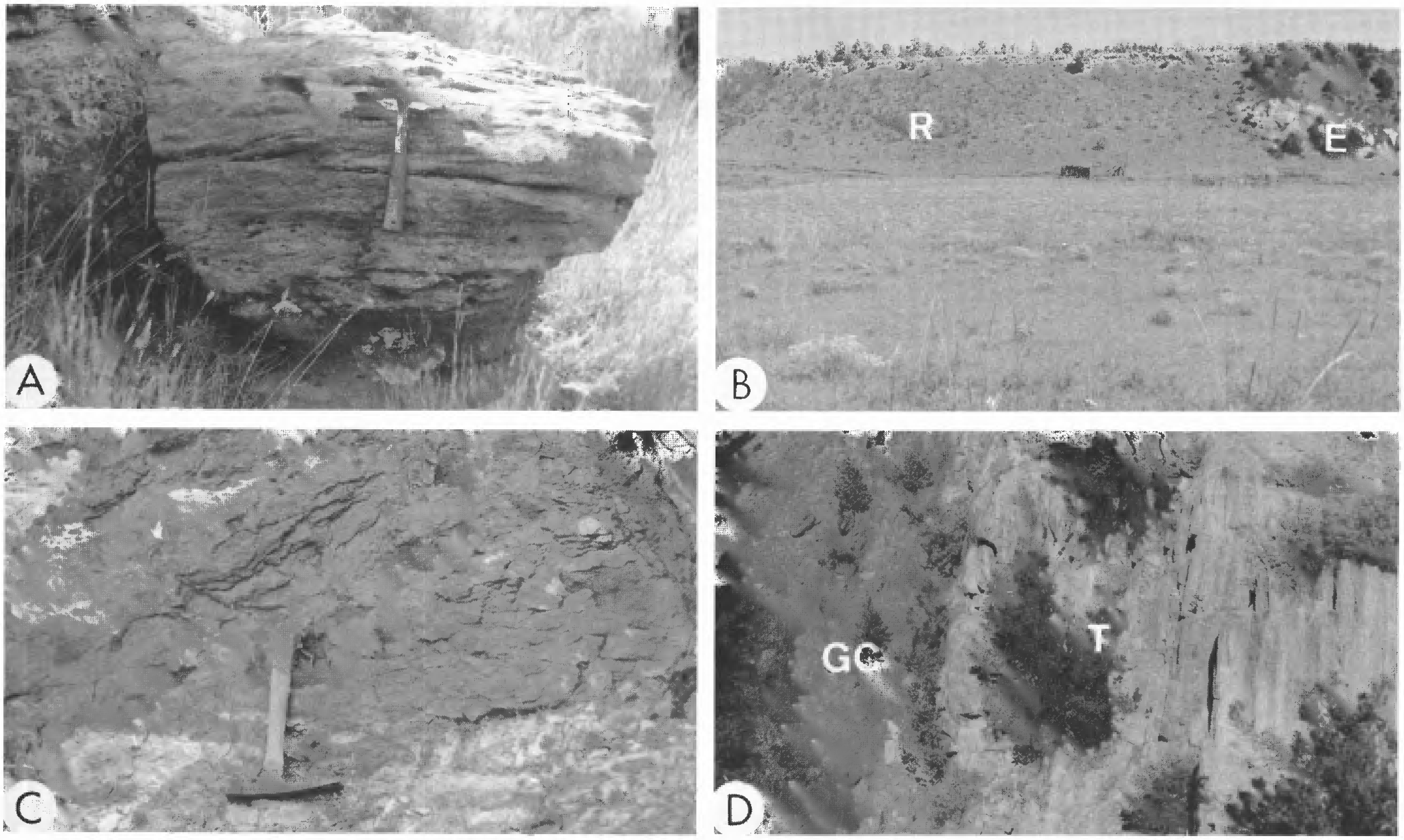


FIGURE 5. Triassic strata near Ocate and Montezuma. A, Trough-crossbedded conglomerate and sandstone of Anton Chico Member of Moenkopi Formation near Ocate. B, View of poorly exposed, Naranjos section of Triassic Redonda Formation (R) overlain by Jurassic Entrada Sandstone (E). C, Typical siltstone of upper part of Redonda Formation near Ocate. D, Overturned strata of Trujillo Formation (T) overlying Garita Creek Formation (GC) at San Sebastian Canyon section.

dominated by grayish-red, pale olive and yellowish-green sandy silstone with lesser amounts of litharenite sandstone and intraformational conglomerate. Lithologic similarity and equivalence of stratigraphic position indicate that the Johnson Gap Formation of our usage is equivalent to the Redonda Formation to the south.

Johnson and Baltz (1960) named the Johnson Gap Formation for Triassic strata exposed at Johnson Gap, secs. 19 and 20, T34S, R69W, Las Animas County, Colorado. At its type section, the Johnson Gap Formation is 27.5 m thick and rests disconformably on the Sangre de Cristo Formation and is disconformably overlain by the Entrada Sandstone (Fig. 2). The type Johnson Gap Formation of Johnson and Baltz (1960) includes strata equivalent to the Trujillo Formation and Johnson Gap Formation of our usage. Their units 1–9 correlate with our units 6–9 in the Ricardo Creek section (Fig. 2; Appendix). In other words, the Santa Rosa and Baldy Hill Formations are not present at Johnson Gap, and the Trujillo Formation rests directly on the Sangre de Cristo Formation.

We restrict the term Johnson Gap Formation to the post-Trujillo portion of the Johnson Gap type section, units 10 and 11 of Johnson and Baltz (1960). This restriction limits the unit to strata we perceive as equivalent to the Redonda Formation in the Tucumcari basin. We did consider abandoning the name Johnson Gap in favor of Redonda. However, there are obvious lithologic differences between the Johnson Gap and Redonda Formations—particularly the presence of conglomerates and immature sandstones in the former—that merit separate formational status. Our restricted use of the term Johnson Gap Formation thus differs from that of previous workers, especially Johnson and Baltz (1960), Baltz (1965), Johnson (1969), Pillmore (1976) and Lucas et al. (1987).

CORRELATION

Correlation of the Triassic strata exposed in the Sangre de Cristo Mountains with Triassic strata exposed on the High Plains (Tucumcari basin and Dry Cimarron Valley) to the east (Fig. 6) is based on lithologic similarity and homotaxis. The basis of age determinations for all Upper Triassic stratigraphic units in the Sangre de Cristo Mountains, which lack age-diagnostic fossils, depends largely on correlations with the equivalent fossiliferous strata of the Tucumcari basin.

The Middle Triassic (Anisian) age of the Anton Chico Member of the Moenkopi Formation is well established in east-central and west-central New Mexico (Lucas and Hunt, 1989; Lucas and Hayden, 1989b). We assume a similar age for Anton Chico strata in the Sangre de Cristo Mountains.

The age of the mottled strata in the Sangre de Cristo Mountains is impossible to determine with any accuracy. This "stratigraphic unit" represents weathering that postdates the Moenkopi Formation of Anisian (Middle Triassic) age and predates the Santa Rosa Formation of late Carnian (Late Triassic) age (see below). Fossil vertebrates (Hunt and Lucas, 1988) and megafossil plants (Ash, 1988) from the Los Esteros Member of the Santa Rosa Formation in the Tucumcari basin indicate it is of late Carnian (Late Triassic) age.

The Garita Creek Formation in the Tucumcari basin contains a small, but age diagnostic, invertebrate and vertebrate fauna (Hunt et al., 1989). This fauna is indicative of a latest Carnian (Late Triassic) age, and we assume a similar age for strata of the Garita Creek Formation in the Sangre de Cristo Mountains. The Baldy Hill Formation occupies the same stratigraphic position as the Garita Creek Formation in parts of the Sangre de Cristo Mountains. However, its lithologic similarity to the Los Esteros Member of the Santa Rosa Formation tentatively leads

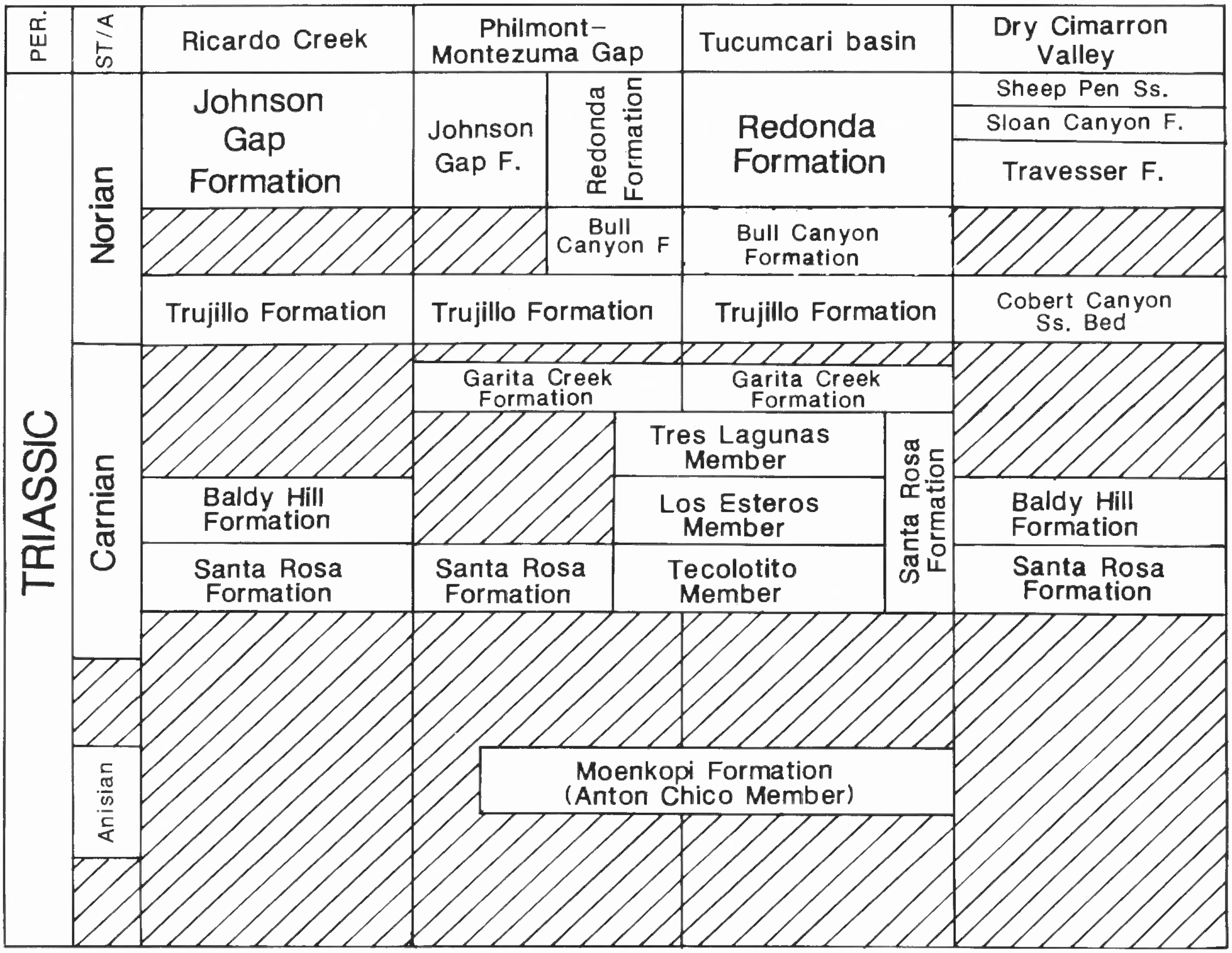


FIGURE 6. Correlation of Triassic strata in the Sangre de Cristo Mountains with Triassic strata in the Dry Cimarron Valley and in the Tucumcari basin of east-central New Mexico.

us to assign a late, but not latest, Carnian age to this unit.

The Trujillo Formation has not yielded any age-diagnostic fossils. However, it overlies the Garita Creek Formation of latest Carnian age and underlies the Bull Canyon Formation of early Norian age. Thus, the Trujillo lies at the Carnian-Norian boundary. The early Norian age of the Bull Canyon Formation is based on a large and diverse vertebrate fauna in the Tucumcari basin (Hunt and Lucas, 1989; Lucas and Hunt, 1989). We extrapolate the age of the Bull Canyon Formation from the Tucumcari basin to the Sangre de Cristo Mountains.

The Redonda Formation in the Tucumcari basin contains a vertebrate trace-fossil and body-fossil fauna indicative of a middle(?) Norian age (Hunt and Lucas, 1989; Lucas and Hunt, 1989; Hunt, 1990). We thus assume that in the Sangre de Cristo Mountains the Redonda Formation and its lateral equivalent, the Johnson Gap Formation, are of ?middle Norian age.

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APPENDIX—MEASURED SECTIONS

The measured sections of Triassic rocks in the Sangre de Cristo Mountains (Fig. 2) are described here. Rock colors follow Goddard et al. (1984).

Montezuma Gap

Measured in the NW1/4 NW1/4 NW1/4 sec. 5 and NE1/4 NE1/4NE1/4 sec. 4, T16N, R16E (unsurveyed), San Miguel County, New Mexico along NM Route 65. Strata dip 87° to S88°W (strata are overturned 30°).

unit	lithology	thickness (m)
	Trujillo Formation:	
22	Sandstone and conglomerate; sandstone is pale olive (10 Y 6/2), quartzose, very fine grained, subrounded, well sorted, calcareous and trough crossbedded; conglomerate is pale greenish-yellow (10 Y 8/2) calcareous stiltstone with light olive-gray (5 Y 5/2) clasts of siltstone up to 1 cm in diameter.	not measured
	Disconformity	
	Garita Creek Formation:	
21	Mostly covered; some grayish red (10 R 4/2) mudstone like unit 20.	20.1
20	Mudstone and sandstone; mudstone is grayish red (10 R 4/2) and not calcareous; sandstone is same color and lithology as unit 19; sandstone and mudstone are intercalated in 0.6-m-thick beds.	3.8

unit	lithology	thickness (m)
	Santa Rosa Formation:	
	Tres Lagunas Member:	
19	Sandstone and mudstone; sandstone is grayish red (10 R 4/2), fine grained, subangular, well sorted, not calcareous, lithic wacke; mudstone is grayish red (5 R 4/2) and not calcareous; mudstone forms 0.1-m-thick partings between 0.6–0.9-m-thick sandstone beds.	4.9
18	Sandstone and conglomerate; sandstone is yellowish gray (5 Y 7/2), fine-medium grained, subrounded, well sorted, not calcareous and quartzose; conglomerate consists of pale olive (10 Y 6/2) matrix identical lithologically to the sandstone and clasts of medium gray (N 5) siltstone up to 1 cm in diameter; conglomerate forms lags at basal scours of trough-crossbedded sets of sandstone.	3.1
	Disconformity	
	Los Esteros Member:	
17	Mudstone and silty mudstone; pale yellowish green (10 GY 7/2); not calcareous.	6.4
	Tecolotito Member:	
16	Sandstone; yellowish gray (5 Y 7/2); quartzose; fine-medium grained, subangular; poorly sorted; not calcareous; laminar.	3.0
15	Sandstone; pale olive (10 Y 6/2); quartzose; very fine-fine grained; subrounded; well sorted; not calcareous; laminar to massive; lens of conglomerate near top of unit has yellowish gray (5 Y 8/1) quartzose, fine-medium grained, angular, poorly sorted sandstone matrix and clasts of moderate yellow (5 Y 7/6) sandstone and black (N 1) carbonaceous debris.	2.2
	Disconformity	
	Mottled Strata:	
14	Sandstone; mottled grayish red purple (5 RP 4/2) and very pale green (10 G 8/2); litharenite; very fine grained; subangular; well sorted; not calcareous; micaceous; bioturbated to massive; thickness varies greatly on strike to as much as 0.9 m.	0.4
	Moenkopi Formation:	
	Anton Chico Member:	
13.	Sandstone; grayish red (10 R 4/2); lithic wacke; very fine-medium grained; subangular; poorly sorted; not calcareous; trough crossbedded.	2.3
12	Covered; some sandstones identical to unit 3 crop out.	7.2
11	Sandstone; grayish red (10 R 4/2); lithic wacke; medium grained; subangular; poorly sorted; not calcareous; trough crossbedded except upper 1.8 m which are laminar.	7.2
10	Sandstone and conglomerate; sandstone is grayish red (10 R 4/2), litharenite, very fine-medium grained, subrounded, poorly sorted, not calcareous and trough crossbedded; conglomerate has grayish red (10 R 4/2), medium-grained, subangular, well sorted, quartzose sandstone matrix and siltstone clasts that are light olive gray (5 Y 5/2) and grayish red purple (5 RP 4/2), calcareous and up to 1 cm in diameter; conglomerate occurs as basal lag of 3 stacked channels that comprise the unit.	4.2
9	Sandstone; grayish yellow green (5 GY 7/2); same lithology as unit 7; has rip-ups of unit 8 that are grayish red (5 R 4/2); unit represents a scour surface.	0.2
8	Sandstone; very dusky red purple (5 RP 2/2); same lithology as unit 3; laminar to massive.	0.7
7	Sandstone; grayish green (10 GY 5/2) and grayish red (10 R 4/2); same lithology as unit 6; unit represents a scour surface.	0.1
6	Sandstone; very pale green (10 G 8/2); litharenite; very fine-fine grained; subrounded; well sorted; calcareous; low angle planar crossbeds.	2.2
5	Sandstone; same color and lithology as unit 3; laminar and ripple laminar.	1.0
4	Silty and sandy shale; grayish red (10 R 4/2) and pale green (5 G 7/2); calcareous; sand is fine-medium grained, subangular quartz and micas; top of unit has thin sandstone ledges identical to unit 3 that are bioturbated.	2.1
3	Sandstone; grayish red (10 R 4/2); litharenite; very fine-fine grained; subrounded; poorly sorted; slightly calcareous; ripple laminar with clay drapes.	0.7
	Disconformity	
	Bernal Formation (Artesia Group):	
2	Sandstone; yellowish gray (5 Y 7/2); quartzose; very fine grained; subrounded; well sorted; slightly calcareous; low angle trough crossbedded.	1.0
1	Sandy siltstone; pale reddish brown (10 R 5/4) and pale olive (10 Y 6/2); calcareous; laminar.	1.8+

San Sebastian Canyon

Measured in the SW¼ NW¼ sec. 32, T17N, R16E (unsurveyed), San Miguel County, New Mexico. Strata dip 75° to S40°W (they are overturned 15°).

unit	lithology	thickness (m)
	Entrada Sandstone:	
23	Sandstone; very pale green (10 G 8/2); quartzose; very fine-fine grained; subrounded; well sorted; massive; forms a hogback.	not measured
	Disconformity	
	Redonda Formation:	
22	Siltstone; moderate reddish brown (10 R 4/6); calcareous; mostly covered.	45.7
21	Sandy siltstone; mottled yellowish green (5 GY 7/2) and grayish red (10 R 4/2); calcareous; ripple laminar; contains some lenses of grayish red (5 R 4/2) clay-pebble conglomerate; forms a hogback.	5.8
20	Mudstone; moderate reddish brown (10 R 4/6); calcareous; some calcite veins.	6.4
19	Clayey siltstone; grayish red (10 R 4/2); calcareous.	0.9
18	Clayey siltstone; moderate reddish brown (10 R 4/6); calcareous.	2.7
17	Clayey siltstone; very pale green (10 G 8/2) with pale reddish-brown (10 R 5/4) mottles; contains nodular calcretes.	2.1
	Disconformity	
	Bull Canyon Formation:	
16	Mudstone; dark reddish brown (10 R 3/4); bentonitic; not calcareous.	14.9
	Trujillo Formation:	
15	Sandstone; grayish yellow green (5 GY 7/2); quartzose; very fine grained; subrounded; well sorted; not calcareous; contains some light bluish-gray (5 B 7/1) siltstone pebbles up to 1 cm in diameter; contains some oxidized plant fragments; trough crossbedded.	4.6
14	Covered; strike valley of mudstone(?).	3.9
13	Sandstone and conglomerate; sandstone is grayish yellow green (5 GY 7/2) and same lithology as unit 10; conglomerate is light olive gray (5 Y 5/2) with siltstone pebbles up to 2 cm in diameter in a matrix of the sandstone lithology; trough crossbedded above basal 1.2 m which are laminar.	8.2
12	Siltstone; grayish red (5 R 7/2); slightly calcareous.	10.4
11	Sandstone; yellowish gray (5 Y 7/2); quartzose; fine-medium grained; subrounded; well sorted; calcareous; trough crossbedded.	6.1
10	Conglomerate; matrix is grayish green (10 GY 5/2), quartzose, medium-grained, subrounded-subangular, well sorted, calcareous sandstone; pebbles are grayish yellow-green (5 GY 7/2) limestone pebbles up to 1 cm in diameter; trough crossbedded.	0.9
9	Sandstone; same color and lithology as unit 11.	3.0
8	Sandstone; pale olive (10 Y 6/2); quartzose; very fine grained; subangular-subrounded; well sorted; micaceous; not calcareous; contains black (N 1) plant debris; laminar and planar crossbedded.	10.0
7	Sandstone; yellowish gray (5 Y 7/2); quartzose; medium grained; subrounded; well sorted; calcareous; massive with clay-ball rip-ups at base.	1.5
6	Sandstone; grayish red (10 R 4/2); litharenite; very fine grained; subangular; well sorted; micaceous; slightly silty; slightly calcareous; laminar and ripple laminar.	6.4

unit	lithology	thickness (m)
5	Silty sandstone and conglomerate; sandstone is grayish red (10 R 4/2), quartzose, fine grained, subrounded, well sorted, slightly calcareous and ripple laminar; conglomerate (basal 1.1 m of unit) is pale green (5 G 7/2) with limestone and siltstone pebbles in a calcareous siltstone matrix.	3.0
	Disconformity	
	Garita Creek Formation:	
4	Mudstone; dark reddish brown (10 R 3/4); calcareous.	5.3
3	Sandstone; grayish red (10 R 4/2); litharenite; very fine-fine grained; subangular; poorly sorted, not calcareous; laminar and ripple laminar.	4.0
2	Muddy siltstone; pale green (5 G 7/2); plant debris; laminar.	5.8
	Santa Rosa Formation:	
	Tres Lagunas Member:	
1	Sandstone and conglomerate; sandstone is pale olive (10 Y 6/2), quartzose, very fine-medium grained, subangular, poorly sorted and laminar; conglomerate is pale greenish yellow (10 Y 8/2) with calcareous siltstone clasts up to 2 cm in diameter in a matrix of the sandstone; contains black (N 1) plant debris.	not measured

La Cueva

Measured in the S½ NE¼ sec. 21, T20N, R16E, Mora County, New Mexico along NM Route 94. Strata dip 40° to due E.

unit	lithology	thickness (m)
	Bull Canyon Formation:	
21	Silty sandstone; banded yellowish gray (5 Y 7/2) and light olive gray (5 Y 5/2); quartzose; very fine grained; subangular; poorly sorted; calcareous; micaceous; trough crossbedded; forms a ridge.	not measured
20	Mudstone; same color and lithology as unit 18.	3.0
19	Sandstone; same color and lithology as unit 17.	0.5
18	Mudstone; grayish red purple (5 RP 4/2); very calcareous.	1.8
17	Sandstone; light olive gray (5 Y 5/2); quartzose; very fine grained; subangular-subrounded; well sorted; ripple laminar and trough crossbedded.	7.5
16	Covered; strike valley probably underlain by mudstone.	16.8
	Trujillo Formation:	
15	Sandstone and conglomerate; sandstone is yellowish gray (5 Y 6/4) quartzose, very fine-fine grained, subangular-subrounded, moderately sorted, micaceous, calcareous and trough crossbedded; conglomerate has matrix that is yellowish gray (5 Y 7/2), quartzose, medium-coarse grained, subangular-subrounded, poorly sorted, not calcareous sandstone and clasts that are pale greenish-yellow (10 Y 8/2), calcareous siltstone and limestone; conglomerate lenses are interbedded with the sandstone.	31.7
14	Conglomerate; matrix is greenish-gray (5 G 6/1), quartzose, medium-coarse grained, subrounded, poorly sorted sandstone and micritic limestone; clasts are yellowish-gray (5 Y 8/1) quartzite; trough crossbedded.	10.5
	Disconformity	
	Garita Creek Formation:	
13	Silty mudstone; very dusky purple (5 P 2/2); not calcareous.	12.5
12	Silty mudstone; grayish purple (5 R 4/2); calcareous; bentonitic.	13.5
	Santa Rosa Formation:	
	Tres Lagunas Member:	
11	Sandstone; same colors and lithology as unit 10; laminar and ripple laminar.	1.0
10	Sandstone; speckled yellowish gray (5 Y 7/2) and light olive brown (5 Y 5/6); quartzose; fine grained; subrounded; well sorted; not calcareous; trough crossbedded.	7.0
	Los Esteros Member:	
9	Mostly covered; what is exposed is silcrete mottled very dusky red purple (5 RP 2/2) and very pale green (10 G 8/2) with some medium-grained, subangular quartz grains.	13.5
	Tecolotito Member:	
8	Sandstone and conglomerate; sandstone is olive gray (5 Y 4/1), quartzose, medium grained, subrounded, moderately sorted, not calcareous and trough crossbedded; conglomerate lenses are silica pebbles of chert, quartzite and petrified wood.	2.5
7	Sandstone; grayish red purple (5 RP 4/2); quartzose; very fine grained; subrounded, well sorted; ferruginous; small trough crossbeds.	7.8
6	Sandstone; yellowish gray (5 Y 7/2) with olive gray (5 Y 3/2) spots; quartzose; very fine-fine grained; subrounded-subangular; moderately sorted; not calcareous; trough crossbedded.	7.5
5	Conglomeratic sandstone; moderate yellowish green (5 GY 7/4); quartzose; very fine-very coarse grained; subrounded; poorly sorted; not calcareous; pebbles are silica; trough crossbedded.	0.6
4	Sandstone; yellowish gray (5 Y 7/2) with olive gray (5 Y 3/2) spots; quartzose; fine-medium grained; subrounded; moderately sorted; slightly calcareous; trough crossbedded; unit has some dispersed quartzite pebbles.	3.3
	Disconformity	
	Moenkopi Formation:	
	Anton Chico Member:	
3	Muddy siltstone and sandstone, partially covered; siltstone is dark reddish brown (10 R 3/4) and not calcareous; sandstone is dark reddish-brown (10 R 3/4), very fine-fine grained, litharenite; sandstone occurs as a few, thin, laminar ledges.	30.5
2	Sandstone; grayish red (10 R 4/2); litharenite; fine-medium grained; subangular-subrounded; poorly sorted; not calcareous; micaceous; trough crossbedded.	16.5
	Disconformity	
	Glorieta Sandstone:	
1	Sandstone; grayish yellow (5 Y 8/4); quartzose; fine grained; subrounded; well sorted; not calcareous; trough crossbedded.	not measured

Naranjos A

Measured in the S½ SW¼ sec. 35, T23N, R18E (unsurveyed), Mora County, New Mexico. Strata dip 30° to S40°E.

unit	lithology	thickness (m)
	Entrada Sandstone:	
6	Sandstone; pale greenish yellow (10 Y 8/2); quartzose; medium grained; subrounded; well sorted; not calcareous; trough crossbedded; forms a cliff.	not measured
	Disconformity	
	Redonda Formation:	
5	Covered slope.	48.0
4	Sandstone; grayish red (10 R 4/2); litharenite; very fine grained; subangular-subrounded; well sorted; not calcareous; trough crossbedded and ripple laminar.	2.5
3	Mudstone; pale reddish brown (10 R 5/4); calcareous.	5.3
2	Siltstone; grayish red purple (5 RP 4/2) and pale greenish yellow (10 Y 8/2); calcareous; some trough crossbeds but generally weathers blocky.	6.0
	Disconformity	
	Bull Canyon Formation:	
1	Mudstone; pale reddish brown (10 R 5/4); calcareous.	not measured

Naranjos B

Measured in the SW¼ NW¼ sec. 4, T22N R18E (unsurveyed), Mora County, New Mexico. Strata dip 30° to S40°E.

unit	lithology	thickness (m)
	Redonda Formation:	
3	Sandy siltstone; grayish red purple (5 RP 4/2); slightly calcareous; weathers "hackly."	10.5
2	Muddy siltstone; moderate reddish brown (10 R 4/6); calcareous; massive with silty dike fractures and veins.	12.5
	Disconformity	

unit	lithology	thickness (m)
Bull Canyon Formation:		
1	Silty mudstone; moderate reddish brown (10 R 4/6); calcareous; mostly covered.	11.0+

Rayado Creek

Measured in the NE1/4 SE1/4 sec. 29 and the NW1/4 SW1/4 sec. 28, T25N, R18E (unsurveyed), Colfax County, New Mexico across Rayado Creek. Strata dip 40° to N20°E.

unit	lithology	thickness (m)
Entrada Sandstone:		
10	Sandstone; yellowish gray (5 Y 7/2); quartzose; fine grained; well sorted; subrounded; not calcareous; trough crossbedded; forms a cliff; "notch" halfway up may be Todilto notch?	not measured
Disconformity		
Johnson Gap Formation:		
9	Sandy siltstone and sandstone; siltstone is grayish red (10 R 4/2) and calcareous; sandstone is same color and lithology as unit 8; mostly covered.	13.5
8	Sandstone and conglomerate; sandstone is grayish red purple (5 RP 4/2), litharenite, fine grained, subrounded, well sorted, calcareous and ripple laminar; conglomerate (basal 0.8 m of unit) is composed of grayish yellow-green (5 GY 7/2) clay pebbles in the sandstone as matrix.	5.2
7	Silty claystone; grayish red (10 R 4/2) with pale olive (10 Y 6/2) reduction spots; calcareous; mostly covered.	14.3
Trujillo Formation:		
6	Sandstone; light olive gray (5 Y 5/2) and grayish red (10 R 4/2); has some siltstone pebbles that are yellowish gray (5 Y 7/2) and carbonaceous debris that is black (N 1); quartzose; fine grained; subrounded; well sorted; micaceous and calcareous; trough crossbedded with major scour surfaces every 0.9 to 1.5 m; top 6 m are platey; forms a prominent cliff; dip changes: strata dip 35° to N80°E.	19.0
Disconformity?		
Garita Creek Formation?:		
5	covered	20.0
Santa Rosa Formation:		
4	Sandstone and conglomerate; sandstone is dusky yellow (5 Y 6/4) and pale olive (10 Y 6/2), quartzose, very fine grained, subrounded, well sorted and trough crossbedded; conglomerate is light olive gray (5 Y 5/2) with limestone pellets up to 1 cm in diameter set in a sandstone matrix; 31.5 m dominated by sandstone are overlain by a 3-m-thick conglomerate overlain by 4 m of sandstone.	38.5
Disconformity		
Moenkopi Formation (Anton Chico Member):		
3	Mudstone; grayish purple (5 P 4/2); calcareous; mostly covered.	not measured
2	Sandstone; grayish red purple (5 RP 4/2); litharenite; very fine grained; subrounded; well sorted; calcareous and micaceous; trough crossbedded; mostly covered.	not measured
Disconformity		
Glorieta Sandstone:		
1	Sandstone; pale olive (10 Y 6/2); quartzose; very fine and fine grained; subrounded; well sorted; calcareous; trough crossbedded.	not measured

Urraca Creek

Measured in the NW1/4 NE1/4 sec. 8, T25N, R18E (unsurveyed), Colfax County, New Mexico, in the roadcuts just north of the South Fork of Urraca Creek. Strata dip 50° to N90°E.

unit	lithology	thickness (m)
Entrada Sandstone:		
19	Sandstone; grayish yellow (5 Y 8/4); quartzose; fine and medium grained; subrounded; well sorted; not calcareous; trough crossbedded.	not measured
Disconformity		
Johnson Gap Formation:		
18	Covered; probably grayish red purple siltstone?	15.0
17	Sandstone; pale yellowish green (10 GY 7/2) with black (N 1) plant debris; litharenite; fine-medium grained; subangular; well sorted; not calcareous; micaceous; laminar and planar crossbedded; plant debris forms some pebbly lenses.	6.0
16	Conglomerate; matrix is dusky yellow (5 Y 6/4), quartzose, very fine-medium grained, poorly sorted micaceous sandstone; clasts are pale olive (10 Y 6/2), calcareous siltstone and limestone pebbles up to 2 cm in diameter; clast supported; trough crossbedded.	1.0
15	Clayey siltstone; grayish yellow green (5 GY 7/2) and grayish red purple (5 RP 4/2); calcareous.	13.5
14	Sandstone; pale olive (10 Y 6/2); quartzose; very fine grained; subrounded; well sorted; not calcareous; trough crossbedded.	6.8
13	Sandy mudstone; grayish purple (5 P 4/2); very calcareous; sandy lenses are same lithology as unit 14 but ripple laminar.	6.3
12	Silty shale; pale olive (10 Y 6/2); calcareous.	4.0
11	Silty mudstone; grayish purple red (5 P 4/2); calcareous; mostly covered.	21.0
10	Silty mudstone; grayish red purple (5 RP 4/2); very calcareous.	6.0
9	Sandy mudstone; grayish yellow (5 Y 8/4); calcareous.	5.3
Trujillo Formation:		
8	Sandstone; dusky yellow (5 Y 6/4) and light brownish gray (5 YR 6/1); quartzose; very fine-fine grained; subrounded; well sorted; very calcareous; trough crossbedded; some lenses are mottled moderate yellowish green (5 GY 7/4) and very dusky purple (5 P 2/2) and consist of medium-coarse grained sand with black (N 1) carbonaceous debris; top of unit is ripple laminar.	8.0
7	Sandy siltstone and thin sandstone lenses; siltstone is mottled dusky yellow (5 Y 6/4) and very dusky red purple (5 RP 2/2) and not calcareous; sandstone is light olive gray (5 Y 5/2); medium-coarse grained, subangular-subrounded, well sorted quartz.	10.5
6	Sandstone; pale greenish yellow (10 Y 8/2); quartzose; medium grained; subrounded; well sorted; not calcareous; slightly clayey; trough crossbedded.	8.8
5	Sandstone and conglomeratic sandstone; sandstone is white (N 9) and light olive gray (5 Y 6/1), fine-very coarse grained, angular, poorly sorted, not calcareous quartz; conglomerate clasts are very light gray (N 8) siltstone; massive.	2.0
Disconformity		
Garita Creek Formation:		
4	Sandy mudstone; grayish red purple (5 RP 4/2); very micaceous; not calcareous; mostly covered.	7.8
Santa Rosa Formation:		
3	Sandstone and conglomerate; sandstone is pale greenish yellow (10 Y 8/2), very fine grained, subrounded, moderately sorted, slightly micaceous, not calcareous quartz; conglomerate has matrix that is pale olive (10 Y 6/2), very coarse grained, angular, poorly sorted, not calcareous quartz and yellowish gray (5 Y 8/1) silica clasts as much as 5 cm in diameter; trough crossbedded.	9.0
Disconformity		
Mottled Strata:		
2	Sandstone; mottled grayish red purple (5 RP 4/2) and grayish green (10 GY 5/2); subarkose; very fine grained; subangular; moderately sorted; slightly micaceous; mostly covered.	2.9
Sangre de Cristo Formation:		
1	Conglomerate; matrix is grayish yellow green (5 GY 7/2), coarse grained, subangular-angular, moderately sorted, micaceous, not calcareous subarkose; clasts are moderate yellowish-green (5 GY 7/4) and grayish red-purple (5 RP 4/2) granite and metamorphics as much as 7 cm in diameter.	not measured

Cimarroncito

Measured in the NW1/4 SW1/4 sec. 6, T 24N, R18E (unsurveyed), Colfax County, New Mexico. Strata dip 40° to N30°E.

unit	lithology	thickness (m)
	Bell Ranch Formation?:	
14	Sandstone and basal conglomerate; sandstone is grayish red (5 R 4/2), very fine grained, subangular, well sorted, trough crossbedded litharenite; conglomerate has dusky yellowish-green (5 GY 5/2) calcareous siltstone matrix, grayish-red (5 R 4/2) calcareous siltstone clasts and is basal 0.3 m of unit.	1.6
13	Covered slope.	8.8
12	Sandstone; pale olive (10 Y 6/2); litharenite; very fine-fine grained; subangular-subrounded; poorly sorted; not calcareous; micaceous; trough crossbedded; mostly covered with a few sandstone ledges exposed.	4.5
	Entrada Sandstone:	
11	Sandstone; light olive gray (5 Y 5/2); quartzose; fine grained; subrounded; well sorted; not calcareous; trough crossbedded; upper half of unit has some blackish red (5 R 2/2) oxidized plant stems.	3.0
	Disconformity	
	Johnson Gap Formation:	
10	Sandstone and conglomerate; sandstone is grayish yellow green (5 GY 7/2), very fine-fine grained, subangular-subrounded, calcareous trough crossbedded quartz; conglomerate is same color and lithology as unit 2; conglomerate and sandstone extensively interbedded and form some swales; base of unit has as much as 0.2 m of scour relief.	1.8
9	Sandy siltstone; mottled grayish purple (5 P 4/2) and moderate yellowish green (5 GY 7/4); calcareous; hackly and bioturbated.	2.4
8	Muddy siltstone; grayish red (10 R 4/2); calcareous; has calcrete nodules that are pale yellowish green (10 GY 7/2), hackly and bioturbated.	10.0
7	Sandy siltstone; grayish red (10 R 4/2); slightly calcareous; laminar; sand is very fine grained quartz.	1.0
6	Silty sandstone and conglomerate; sandstone is grayish red (5 R 4/2), very fine grained, subangular-subrounded, poorly sorted, slightly calcareous, trough crossbedded litharenite; conglomerate is same color and lithology as unit 2; conglomerate forms thin lenses in trough bases.	1.4
5	Interbedded muddy and sandy siltstone; grayish red (5 R 4/2); calcareous, muddy layers are hackly to laminar; sandy layers are hummocky to trough crossbedded.	5.0
4	Sandy siltstone; greenish gray (5 GY 6/1) and grayish red (10 R 4/2); slightly calcareous; laminar.	1.0
3	Silty sandstone; grayish red (5 R 4/2); litharenite; very fine-fine grained; subangular-subrounded; well sorted; slightly calcareous; trough crossbedded with some laminar beds.	3.6
2	Conglomerate; greenish gray (5 GY 6/1); matrix is calcareous, micaceous siltstone; clasts are mostly limestone pebbles but include balck, carbonaceous debris.	0.3
1	Siltstone, grayish purple (5 P 4/2); calcareous.	not measured

Ricardo Creek

Measured in the NW1/4 NE1/4 sec. 28, T32N, R17E, Colfax County, New Mexico. Pillmore (1976) located this section in NW1/4 sec. 21, T32N, R17E. Strata are overturned 30° to S40°W.

unit	lithology	thickness (m)
	Entrada Sandstone:	
15	Sandstone; moderate yellowish green (5 GY 7/4); quartzose; fine and medium grained; subrounded; moderate sorting; not calcareous; trough crossbedded.	not measured
14	Sandstone; pale olive (10 Y 6/2); quartzose; fine and medium grained; subangular-subrounded; poorly sorted; calcareous; some feldspars; contains grayish yellow green (5 GY 7/2) siltstone clasts; unit is reminiscent of the Iyanbito Member of the Entrada Sandstone in west-central New Mexico.	0.3
	Disconformity	
	Johnson Gap Formation:	
13	Sandstone and clay-pebble conglomerate; sandstone is grayish red purple (5 RP 4/2) and grayish green (10 GY 5/2), very fine and fine grained, subrounded, moderately sorted, calcareous, ripple laminar, litharenite; conglomerate (basal 0.3 m of unit) has a calcareous siltstone matrix that is pale green (5 G 7/2) and clay clasts that are up to 1 cm in diameter and grayish purple (5 RP 4/2).	2.8
12	Silty mudstone; grayish red purple (5 RP 4/2) with sandy reduction spots that are pale green (5 G 7/2); slightly calcareous.	3.6
11	Siltstone; grayish purple (5 R 4/2); slightly calcareous; trough crossbeds and laminar.	6.4
10	Clayey siltstones; light olive gray (5 Y 5/2); calcareous; some lenses of very fine-grained, angular, micaceous, quartz sandstone; laminar.	1.3
9	Sandstone and conglomerate; sandstone is grayish purple (5 P 4/2), very fine to medium grained, subangular, poorly sorted, micaceous, quartzose and trough crossbedded to laminar; conglomerate (in lenses) has a grayish yellow green (5 GY 7/2) matrix of sandstone with siltstone clasts that are very dusky red purple (5 RP 2/2) and up to 1 cm in diameter.	1.3
	Trujillo Formation:	
8	Sandstone and silty sandstone; sandstone is grayish yellow green (5 GY 7/2), very fine grained, subrounded, well sorted, quartzose, calcareous and trough crossbedded; silty sandstone is grayish green (10 GY 5/2) and (5 G 5/2), very fine grained, subrounded, moderately sorted, quartzose, calcareous and trough crossbedded; unit is very micaceous and has numerous, black (N 1) carbonaceous flecks.	1.5
7	Sandstone; grayish green (10 GY 5/2); quartzose; very fine-fine grained; subrounded; well sorted; calcareous; micaceous; trough crossbedded; contains some conglomerate identical in lithology and color to unit 6; has much black (N 1) plant-stem debris.	9.0
6	Conglomerate; grayish green (10 GY 5/2); matrix is fine to medium grained, subangular, poorly sorted, clayey quartz sand; clasts are limestone as much as 2 cm in diameter; contains some fragments of unionid shells.	1.4
	Disconformtiy	
	Baldy Hill Formation:	
5	Siltstone and sandy/silty mudstone; mottled pale olive (10 Y 6/2), grayish purple (5 P 4/2), grayish red purple (5 RP 4/2) and grayish yellow green (5 GY 7/2); calcareous; contains lenses of sandstone that are very fine grained quartz; massive and bioturbated.	13.0
	Santa Rosa Formation:	
4	Sandstone; yellowish gray (5 Y 7/2) with angular pebbles that are yellowish gray (5 Y 7/2) and pale red purple (5 RP 6/2); quartzose; very coarse grained; angular; poorly sorted; slightly calcareous; trough crossbedded.	3.5
	Disconformity	
	Mottled Strata:	
3	Conglomerate; matrix is grayish yellow green (5 GY 7/2), fine to coarse grained, angular, poorly sorted, quartz sandstone; clasts are grayish red purple (5 RP 4/2) and grayish yellow green (5 GY 7/2) quartzite as much as 4 cm in diameter; massive to bioturbated.	4.0
	Sangre de Cristo Formation:	
2	Sandy siltstone; dark reddish brown (10 R 3/4); micaceous; not calcareous.	1.3
1.	Conglomeratic sandstone; matrix is grayish red purple (5 RP 4/2), medium to very coarse grained, angular, poorly sorted arkosic sandstone; clasts are very dusky red purple (5 RP 2/2) and bluish white (5 B 9/1), angular pebbles of quartzite and quartz as much as 2 cm in diameter; clast supported, massive; looks like a debris flow deposit.	not measured