

NEW MEXICO BUREAU OF GEOLOGY AND MINERAL RESOURCES A DIVISION OF NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY

Base map from U.S. Geological Survey 1984, from photographs taken 1976, field checked in 1976, edited in 1984
1927 North American datum, UTM projection zone 13N
1000-meter Universal Transverse Mercator grid, zone 13, shown in red

NEW MEXICO

FRENCH MESA	LAGUNA PEAK	ECHO AMPHITHEATER
GALLINA	Arroyo del Agua	YOUNGSVILLE
NACIMIENTO PEAK	JAROSA	CERRO DEL GRANT

**QUADRANGLE LOCATION** 

This draft geologic map is preliminary and will undergo revision. It was produced from either scans of hand-drafted originals or from digitally drafted original maps and figures using a wide variety of software, and is currently in cartographic production. It is being distributed in this draft form as part of the bureau's Open-file map series (OFGM), due to high demand for current geologic map data in these areas where STATEMAP quadrangles are located, and it is the bureau's policy to disseminate geologic data to the public as soon as possible. After this map has undergone scientific peer review, editing, and final cartographic production adhering to bureau map standards, it will be released in our Geologic Map





1 KILOMETER CONTOUR INTERVAL 20 FEET NATIONAL GEODETIC VERTICAL DATUM OF 1929 New Mexico Bureau of Geology and Mineral Resources

1:24,000

Open-file Map Series **OFGM 124** 

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phenocrysts; sanidine may display a blue iridescence. Contains abundant accidental lithic and Obradovich, 1994; Spell et al., 1996). Up to 65 m thick .

with the Puyé Formation in the northeastern Jemez Mountains.



# Geologic map of the Arroyo del Agua quadrangle, Rio Arriba County, New Mexico

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of the National Cooperative Geologic Mapping Act, administered by the U. S. Geological Survey, and by the New Mexico Bureau of Geology and Mineral Resources, (Dr. Peter A. Scholle, Director and State Geologist, Dr. J. Michael Timmons, Geologic Mapping Program Manager).

## Unit Descriptions for the Arroyo del Agua 7.5' quadrangle

## **Orf Rock Fall (Holocene).** Building-sized blocks of Poleo Formation that have broken away from the edge of the sandstone cliff in the recent past (0358913 N 4003825

E, NAD 27); the Ponderosa pine trees affected by the fall are dead, but the wood decay **Qsly** Young landslide deposit (Holocene). Unconsolidated, hummocky deposit of

4002658 E, NAD 27); vegetation on the deposit is not fully reestablished and Poleo **Qal** Alluvium (Holocene). Unconsolidated clay, silt, sand, and gravel deposited in

Qes Eolian and alluvial deposits (Holocene). Unconsolidated windblown tan-tobrown silt and clay deposited in low-elevation spots and on pediment surfaces. Fluvially reworked; contains lenses of gravel. Usually 1 to 3 m thick, but can be 10 m thick. **Oc Colluvium (Holocene).** Hillslope colluvial deposits composed of pebble to boulder size, unconsolidated debris derived from local volcanic and sedimentary rocks. **Qcbt** designates colluvium composed mainly of Bandelier Tuff. **Qc** refers to colluvium Qt<sub>n</sub> Terrace deposits (middle Pleistocene to Holocene). Alluvial silt, sand, cobble,

and boulder deposits of rounded to subrounded local Mesozoic sandstone and wellrounded Proterozoic quartzite recycled out of older (Permian Cutler Group or Miocene Abiquiu Formation) deposits. The two highest terraces contain 10 to 20% Pedernal Chert derived from the Miocene Abiquiu Formation. At least three terrace levels (1 = oldest, 3 =youngest) are present along the Rio Puerco and Salitral Creek, one at 49 m, one at 36 m,

**Qp**<sub>n</sub> **Pediment gravels (middle Pleistocene to Holocene).** Unconsolidated deposits of angular to subangular pebbles to boulders of Mesozoic sandstone, limestone and gypsum resting on surfaces graded to the level of the highest terraces (1 = oldest, 3 =youngest. The largest surface, covering several  $km^2$ , is on Poleo Mesa, which is cut on the approximate contact between the Poleo and Petrified Forest formations of the Chinle Group. Most of the Poleo Mesa pediment surface is covered with eolian silt (Qe).

Q1s Landslide deposits (middle Pleistocene to Holocene). Unconsolidated, unsorted deposits composed of locally derived, relatively cohesive blocks of bedrock. Landslides along the escarpment of the Rio Puerco in the south-central part of the quadrangle are composed of blocks of Poleo Formation, which typically are rotated so that tops of the blocks dip toward the canyon rim, and the slides sole into the underlying shales of the Salitral Formation. Numerous remnants of once extensive landslide deposits are preserved on and along the base of Mesa Alta escarpment in the northern part of the quadrangle. The base of the landslides often rests on shales of the Jurassic Summerville Formation or Triassic Chinle Group, and top is typically hummocky. The distinctive composition of these landslides, made up of gypsum, limestone, and sandstone debris, indicates they were derived locally from Jurassic and Cretaceous strata to the north. These landslides were deposited either on older alluvium (Qoa) sediments or directly upon mudstone of the upper Chinle Group. Remnants commonly possess a sinuous, linear distribution extending away from the escarpment. The landslide debris appears to have, in places, flowed in narrow channels incised into **Qoa** and **TRcu** that parallel, but are topographically above, the present system of arroyo drainages. These deposits may

**Qoa Older Alluvium (middle to late Pleistocene)**. Ridgely (1979) used the term "older alluvium" for unconsolidated Quaternary sediments on the Arroyo del Agua quadrangle between the Mesa Alta escarpment, northern Mesa Montosa, and Salitral Creek. This unit is composed of two distinct, but complexly interbedded facies that are not mapped separately. One facies, which can make up more than 50% of the deposit, is a brown to reddish-brown siltstone with scattered lenses of gypsum and sandstone gravel and carbonate nodules. The red-brown silt is likely reworked from upper Chinle Group mudstone. Paleosols are frequently preserved. Black to dark brown siltstones interbedded with white fine-grained carbonate deposits that superficially resemble volcanic ash are present in at least four localities across the area. The fine-grained facies most commonly overlies the second facies, but in places, it underlies it. The second facies is a sandy to silty, pebble to cobble unconsolidated gravel in channels that cut either into the underlying Petrified Forest Formation of the Chinle Group or into the fine-grained facies. Cut-and-fill channel structures are common. The rounded to angular clasts in the gravel are local Mesozoic sandstone, limestone, or gypsum. The clasts are generally < 20cm, but boulders up to <80 cm can occur locally. Minor amounts of well-rounded pebbles of Precambrian quartizte are locally present in the gravel. These pebbles are likely to have been derived from conglomeratic beds in the Cretaceous Burro Canyon Formation. The older alluvium is present south of the east-west oriented Mesa Alta escarpment that dominates the northern part of the quadrangle, and the alluvial units appear to be juxtaposed against the upper Chinle Group and are clearly overlain by landslide deposits derived from the escarpment. The clasts become more rounded south of the escarpment. In places, the upper fine-grained facies appears to form a fan that dips 5 to  $10^{\circ}$  south or southeast of the escarpment. Pebble imbrication measurements suggest a meandering braided stream channel system trending southeast. Where exposed along incised arroyos,

**Qb** Bandelier Tuff (early Pleistocene). Pumaceous air-fall tephra, nonwelded to weakly welded rhyolitic ash-flow tuff, and local volcaniclastic sediments; divided into

**Qbt Tshirege Member.** White to orange to pink non-welded to weakly welded rhyolitic, ash-flow tuff (ignimbrite). The tuff contains abundant phenocrysts of sanidine and quartz, rare microphenocrysts of black clinopyroxene, trace microphenocrysts of hypersthene and fayalite, and pumice fragments in a fine-grained matrix of vitric ash. The sanidine typically displays blue iridescence. The tuff is composed of multiple flow units in a compound-cooling unit (Smith and Bailey, 1966; Broxton and Reneau, 1995); includes basal white pumiceous tephra deposits (1-2 m thick) of the Tsankawi Pumice. Qbt forms conspicuous orange to tan cliffs on Loma Redonda and along the southern edge of the quadrangle, east of Mesa Ojitos, where the tuff infills a rugged northeast-trending paleocanyon.  ${}^{40}\text{Ar}/{}^{59}\text{Ar}$  age is  $1.22 \pm 0.01$  Ma (Izett and Obradovich, 1994; Spell et al., 1996). Up to 75 m thick. **Qbo Otowi Member.** White to pale pink, generally poorly welded rhyolitic ash-flow tuff containing abundant phenocrysts of sanidine and quartz, and sparse mafic

fragments; consists of multiple flow units in a compound cooling unit. The stratified pumice fall and surge deposit at base of unit (Guaje Pumice) is not found in this area. Qbo discontinuously fills in rugged topography on a pre-Toledo caldera age volcanic surface and the upper surface can be quite undulatory due to erosion. Qbo disontinuously caps Ojitos Mesa and fills an inset valley along the southeast edge of the quadrangle. Very difficult to distinguish from upper Bandelier Tuff in hand samples; best distinguished by poorer degree of welding, greater tendency to form slopes instead of cliffs, more abundant lithic fragments, less abundant iridescent sanidine, and stratigraphic position beneath the Tsankawi Pumice.  ${}^{40}$ Ar/ ${}^{39}$ Ar ages 1.61± 0.01 to 1.62±0.04 Ma (Izett

**Quaternary to Tertiary** QTg Fluvial gravel (early Pleistocene to Pliocene). Unconsolidated subround fluvial gravel is present under the Otowi Member of the Bandelier Tuff on Triassic Chinle Group strata on Ojitos Mesa. The gravel is composed primarily of clasts of Pedernal Chert, Pennsylvanian limestone, and Proterozoic granite and quartzite clasts recycled out of the lower Abiquiu Formation. This gravel, which is up to 2 m thick, may correlate

Cretaceous

Cretaceous stratigraphy on the Arroyo del Agua quadrangle follows that of Landis and Dane (1967), Saucier (1974) and Owen et al. (2005). The intertongued Dakota Mancos succession is referred to here as the Dakota Formation for mapping purposes, because most of the Dakota members and all of the Mancos members are generally too thin to map separately. Furthermore, the Mancos member that is present (Clay Mesa member) is very sandy, so it is treated as a member of the Dakota Formation. Kd Dakota Sandstone (Late Cretaceous). (includes Clay Mesa Member of Mancos

Shale, of the intertongued Dakota-Mancos succession). Tan to yellow-brown quartzose sandstone, dark gray and brown carbonaceous shale, and minor greenish gray mudstone and bentonite. Members include, from lowest to highest (oldest to youngest): Encinal Canyon, Oak Canyon, Cubero, and Paguate members. The Encinal Canyon Member is highly variable in thickness, ranging from 0 to 18 m and averaging 2 to 4 m. This tan cross-bedded quartz sandstone, with thin to medium bedding, commonly has woody plant impressions at the upper contact. Bioturbation is not common in the Encinal Canyon Sandstone. The fine- to medium-sized sand grains are subangular to subround and wellsorted. The Oak Canyon Member is a black, muddy siltstone interbedded with thin (<1 m) beds of ledgy and often lenticular, white to orange, cross-bedded, bioturbated sandstone. The Cubero Member is a white, massive, thick-bedded, bioturbated sandstone that is 7-8 m thick. The Clay Mesa Member (of the Mancos Shale) is black sandy shale to shale with thin (2-3 cm) beds of ripple-laminated sandstone that is 1-3 m thick. The Paguate Member is orange to tan, with fine-to medium- grained, subangular, well-sorted sand grains. The Paguate Sandstone is often intensely bioturbated, but in places remnant cross-bedding, ripple marks, and thin to thick bedding is preserved. It forms a bold cliff along exposed escarpments of Mesa Alta and is 25-30 m thick. The Dakota Sandstone is 40 to 56 m thick.

Kbc Burro Canyon Formation (Early Cretaceous). White, light yellow, orange, and buff, conglomeratic sandstone with thin lenses of pale green and pink mudstone (Saucier, 1974). Small-scale trough cross-bedding and cut-and-fill structures are associated with the conglomeratic channels. Petrified wood is locally present in gravels. Conglomerate clasts are mostly varicolored quartizte and chert pebbles up to 2.5 cm in diameter, with minor sandstone and limestone clasts. Chert gravel is present fairly uniformly throughout the unit vertically, in contrast to the Ghost Ranch area, where gravel is rare in the upper part of the unit. Pebbly conglomerate makes up less than 50% of the unit. Laminar lowangle wedge and high-angle planar wedge cross-bedding is common in the sandier portions of the formation. The sandstone is fine to medium grained, quartzose, and kaolinitic. locally containing a minor percentage of quartz and chert granules and pebbles. 40 to 50 m thick.

### Jurassic stratigraphy on the Arroyo del Agua quadrangle follows Lucas et al. (2005a), which is based on the regional stratigraphy of Anderson and Lucas (1992, 1994, 1995, 1996, 1997) and Lucas and Anderson (1997, 1998).

Jm Morrison Formation - Brushy Basin Member. (Late Jurassic). All Morrison strata on the Arroyo del Agua quadrangle are assigned to the Brushy Basin Member, which is a variegated pale greenish gray, grayish yellow green, pale olive, yellowish brown, and pale reddish brown bentonitic mudstone with a few beds of trough crossbedded pebbly sandstone. Locally, the base of the Morrison Formationis a thin (up to 8 m thick) interval of trough-crossbedded sandstone and interbedded mudstone. This basal interval is likely correlative to the Salt Wash Member of the Morrison Formation to the west and south. However, this interval is neither thick enough, persistent enough, nor lithologically distinctive enough to separate from the Brushy Basin Member. The upper part of the Brushy Basin is, in places (e.g., 353408 4011319 to 352908 4010853, NAD 27), dominated by an interval that is  $\sim 30$  m thick composed of white to pale green sandstone interbedded with green siltstone that may be correlative to the Jackpile Member of the Morrison Formation in the southern San Juan Basin. The sandstone in the upper part of the interval is a pale green, thin to medium tabular bedded, medium to very fine-grained litharenite with well-sorted, subrounded quartz grains. The lower part of the interval consists of 3 m thick beds of cross-bedded white to red, medium-grained, well-

rounded, well-sorted, litharenite that is conglomeratic at the base; the clasts are intrabasinal siltstone. Total Morrison thickness up to 85 m thick. Js Summerville Formation (Middle to Late Jurassic). (includes the Bluff Sandstone (Late Jurassic), because the Bluff Sandstone is difficult to trace laterally). The Bluff Sandstone is light gray, very fine grained, well sorted sandstone with crossbeds in thick sets. Consists of two members not mapped separately. The lower, Junction Creek Member comprises most of the formation (30-40 m thick) and is mostly pale yellowish green and light olive gray, very fine grained, well sorted sandstone with crossbeds in thick sets. These are primarily eolian deposits similar to the type section of the Junction Creek Member near Durango, Colorado (Goldman and Spencer, 1941). The overlying Recapture Member is 6 to 14 m thick and is mostly maroon, pale brown, grayish red, and light greenish gray gypsiferous siltstone, fine-grained sandstone and mudstone. Recapture strata lithologically resemble underlying Summerville strata. Their fine-grained gypsiferous lithotypes indicate that these strata do not belong to the Morrison Formation (contra Ridgely, 1977, 1979), but instead are assigned to the Recapture Member of the

Bluff Sandstone (Lucas and Anderson, 1997, 1998; Lucas et al, 2005). 44 to 47 m thick. The Summerville Formation below the Bluff interval is thinly and cyclically bedded, maroon, grayish red and yellowish gray siltstone, sandy siltstone, fine gypsiferous sandstone and mudstone. In the Chama Basin, the Summervile Formation (as used by Lucas and Anderson, 1998; Lucas et al., 2005) consists of two, lithologically-distinct units that Lucas et al. (2005) referred to informally as the lower and

upper members. These two units merit formal recognition because of ther distinctiveness

and ready recognition in quadrangle-scale mapping. As Lucas et al. (2005) noted, the lower member of the Summerville Formation in the Chama Basin is the same unit that Goldman and Spencer (1946) named the "Bilk Creek Sandstone Member of the Morrison Formation" in the Telluride-Durango area of southwestern Colorado. Therefore, we apply Goldman and Spencer's (1941) name to the lower member of the Summerville Formation in the Chama Basin. Here, the Bilk Creek Member of the Summerville Formation is ~ 12-15 m thick and is repetitively-bedded gyspiferous sandstone, siltstone, and limestone that forms a ribbed cliff or slope. This yellowish green to light brown unit overlies the Tonque Arroyo Member of the Todilto Formation and locally appears to interfinger with it. The overlying Mesa Alta Member of the Summerville Formation (named here) overlies the Bilk Creek Member in the Chama

We name the upper member of the Summerville Formation in the Chama Basin the Mesa Alta Member. The name is for Mesa Alta on the Arroyo del Agua quadrangle where the type section of the unit is located (sec. 19-20, T23N, R3E). The type section is units 15-25 of the Mesa Alta measured section of Lucas et al. (2005, p. 190, fig. 3). At the type section, the Mesa Alta Member is ~ 96 thick, which appears to be a maximum thickness in the Chama Basin, where the unit is 61-96 m thick. The type section is interbedded siltstone, gypsiferous sandstone and mudstone that forms a grayish red- and white-banded slope between the Bilk Creek Member (below) and the Bluff Sandstone (above). In the Four Corners, and across much of southeastern Utah, the Summerville Formation has been divided into two members—the Beclabito (lower) and Tidwell

(upper) members (Lucas and Anderson, 1997). These members, however, are not the same two Summerville members that are present in the Chama Basin. Thus, the Tidwell Member is mostly laterally equivalent to the Bluff Sandstone (Lucas and Anderson, 1997), so that the Summerville Formation in the Chama Basin is equivalent to the Beclabito Member to the northwest. Strata we term Summerville Formation were assigned to the Morrison Formation by Smith et al. (1961) and Ridgley (1977, 1979), although Ridgley (1989) did assign what we term the lower member of Summerville Formation to the Wanakah Formation. 74 to 111 m thick.



Lucas et al. (2003, 2005b). scale, from younger to older:

The Poleo Formation is about 48 m thick

(2005) and Lucas et al., 2005).







### NMBGMR Open-file Map Series OFGM-124 Last Modified 05 March 2014

**Todilto Formation (Middle Jurassic).** The Todilto Formation consists of a lower, limestone-dominated interval (Luciano Mesa Member, Jt (ls)) overlain locally by a gypsum interval (Tonque Arroyo Member; (Jtg) (Lucas et al., 1985, 1995; Kirkland et al., 1995). The Luciano Mesa Member is 2 to 8 m thick and consists mostly of thinly laminated, dark gray or yellowish gray, kerogenic limestone. Beds near the base of the member are usually sandy, and microfolding of the thin limestone laminae is common. The overlying Tonque Arroyo Member is up to 30 m of white to light gray gypsum interbedded with carbonate. A thin limestone bed (0.5 to 2.0 m) is deposited on the gypsum of the Tonque Arroyo Member in many places along the Mesa Alta escarpment.

Arroyo del Agua area: (1) gypsum interbedded with carbonate is preserved (classic Tonque Arroyo Member); (2) a limestone microbreccia left by dissolution the gypsum of the Tonque Arroyo Member is present; or (3) the Tonque Arroyo member is interbedded with a green to red medium-grained quartz sandstone in two places along the escarpment (344730 4009647, 347100 4009590). Thus, the Todilto Formation in the vicinity of Arroyo del Agua contains a record of places where gypsum was deposited and is still preserved, areas where the gypsum was deposited, but has since dissolved away, and places where the gypsum is interbedded with clastic shoreline deposits. A chaotic brecci that contains angular blocks up to 1 m across is often preserved along the contact between the limestone microbreccia and overlying basal Summerville sandstone. The breccia can contain blocks of: (1) basal Summerville sandstone only; (2) blocks of Summerville sandstone and limestone mircrobreccia; or (3) blocks of Summerville sandstone and the gypsum-capping limestone. The timing of brecciation post-dates the lithification of both the limestone and the sandstone, as well as the microbreccia-forming

Je Entrada Sandstone (Middle Jurassic). Trough crossbedded and ripplelaminated, cliff-forming sandstone. The Entrada Sandstone (only the Slick Rock Member is present in the Chama Basin: Lucas et al., 2005a) is 60 to 76 m of very fine- to mediumgrained, moderately well sorted sandstone that forms bold cliffs along escarpments and mesa tops. Trough crossbeds and ripple laminations are the dominant bedforms. Colors are shades of yellow, light brown and grayish orange. Up to 76 m thick.

All Triassic strata on the Arroyo del Agua quadrangle are assigned to the Upper Triassic Chinle Group (Lucas, 1993). Triassic stratigraphy follows Lucas and Hunt (1992) and **TRc** Chinle Group (Late Triassic). Three informal units are mapped at the 1:24,000

TRcu an informal upper unit that contains the Rock Point Formation and the **Petrified Forest Formation.** (where exposure permits the Petrified Forest Formation is divided into the Painted Desert Member (**TRcpd**) and the Mesa Montosa (**TRcm**) member). The stratigraphically highest unit in the Chile Group is the Rock Point Formation, a reddish brown to gray-red siltstone and fine-grained sandstone. The sandstone can locally be a coarse-grained sandstone or a granule conglomerate. The thinly interbedded sandstone and siltstone beds form a ribbed cliff where the Rock Point outcrop is not deeply weathered. Where weathered, the Rock Point Formation is an orange slope. The Rock Point base is the first persistent bed of sandstone above slopeforming mudstone of the Painted Desert Member of the Petrified Forest Formation. The top of the Rock Point is a sharp contact with the overlying eolian sandstone of the Slick Rock Member of the Jurassic Entrada Sandstone. The Rock Point Formation in the Chama Basin is up to 30 m thick (Lucas et al., 2003). The Petrified Forest Formation, which is reddish-brown bentonitic mudstone that forms extensive slopes and dissected badland areas where exposed, consists of two members, the Painted Desert Member (**TRcpf**) and the Mesa Montosa (**TRcm**) member. The overlying Painted Desert Member is up to 176 m of reddish brown, bentonitic mudstone and thin ledges and lenses of ripple-laminated or crossbedded sandstone. Its base is a thick mudstone bed above the highest sandstone ledge of the Mesa Montosa Member. Its top is a sharp contact with siltstone/sandstone of the Rock Point Formation (locally), or sandstone of the Jurassic Entrada Sandstone can rest directly on the Painted Desert Member. In the vicinity of 349493 4008607 (NAD27), downward tapering wedges of sandstone that are 0.5 to 1 m long are present in the mudstone of the Painted Desert Member at the Painted Desert Member/Entrada contact. We interpret these as sandstone dikes that filled fissures in the underlying lithified Chinle Group strata when the Entrada Sandstone was deposited on the J-2 unconformity surface that separates the Chinle and Entrada. The lower, Mesa Montosa Member is made of up to 24 m of mostly sandstone and lesser amounts of mudstone and siltstone that range in color from reddish brown to green; the sandstone beds are typically ripple-laminated to thinly-laminated. The Mesa Montosa Member forms a ribbed slope, 4 to 24 m thick, between coarser-grained Poleo Formation sandstone below, and slope-forming mudstone of the Painted Desert Member of the Petrified Forest Formation above. The Petrified Forest Formation is up to 200 m thick. TRcp Poleo Formation. Yellow-brown, yellow- gray, white and red, medium to fine-grained, micaceous, cross-bedded, quartzose sandstone, conglomeratic sandstone and conglomerate. The conglomerate in the Poleo Formation is is often black and

contains both intrabasinal siltstone and nodular calcrete clasts and extrabasinal siliceous (chert and quartzite) clasts. This unit forms prominent white cliffs. The base of the unit is sharp (corresponds to the Tr-4 unconformity of Lucas, 1993) and the upper contact is gradational into the overlying Mesa Montosa Member of the Petrified Forest Formation. TRcl an informal lower unit that contains the Salitral Formation and the

**Shinarump Formation.** The Salitral Formation is dominantly green, purple and red smectitic mudstone with calcrete nodules. The unit tends to be olive gray to reddishbrown silty mudstone near the base (Piedra Lumbre Member) and a maroon to reddishbrown mudstone (Youngsville Member) near the top. An orange chert bed that is 2 to 20 cm thick is common in the Piedra Lumbre Member. A sandstone bed at the top of the Piedra Lumbre Member, the El Cerrito Bed, is a local yellow to reddish brown conglomeratic sandstone that is as much as 10 m thick on Mesa Montosa. The base of the El Cerrito bed marks a profound change in the degree of alteration of the rocks by paleoweathering during Triassic time. Below the El Cerrito bed, both the Shinarump Formation and the Piedra Lumbre Member of the Salitral Formation can be mottled; mottling is rare above the base of the El Cerrito Bed. The Salitral Formation varies greatly in thickness, ranging from 3 to 30 m. The Shinarump Formation (= Agua Zarca Formation of previous usage: e.g., Wood and Northrop, 1946; Dubiel, 1989; Lucas and Hunt, 1992) consists of white, red, orange, and brown quartz sandstone, conglomeritic sandstone, and extrabasinal conglomerate that includes clasts of quartz, chert, and quartzite (Lucas et al., 2003) interbedded with or sitting on olive gray to reddish-brown silty mudstone. Local mineralization (copper, uranium) produces colors that range from black to yellow to green. Trough crossbeds are the dominant bedform. Petrified wood is rare. The basal contact is sharp; the basal contact corresponds to the Tr-3 unconformity of Pipiringos and O'Sullivan (1978) and Lucas (1993). Sandstone beds in the Shinarump Formation are absent to thin (1 to 2 m) in the Rio Puerco valley, but locally are as much as 20 m thick. In many places in the Rio Puerco valley, color-mottled shale of the Shinarump Formation sits directly on altered, weathered Yeso Group or uppermost Cutler Group; the Shinarump sandstone may be absent or channel sandstone of Shinarump lithology may be 2 to 4 m above the contact with the Permian rocks.

**Pennsylvanian-Permian** The oldest strata exposed on the Arroyo del Agua quadrangle are Pennsylvanian-Permian siliciclastic red beds of the Cutler Group (Cutler Formation of Smith et al., 1961) and overlying Yeso Group. Stratigraphy employed here follows Lucas and Krainer

**Py Yeso Group (Early Permian)**. Orange-red medium-grained, moderately to wellsorted sandstone with large-scale (eolian) crossbeds, or more rarely, laminated sand sheet bedding. These strata are equivalent to the De Chelly Sandstone of the Yeso Group (Baars, 1962; Krainer et al. 2005) (Meseta Blanca Member of the Yeso Formation of Northrop and Wood, 1946). The eolian sandstone gradationally overlies or is interbedded with the arkosic fluvial deposits of the Arroyo del Agua Formation and is overlain with prominent unconformity by basal strata of the Chinle Group. The unit thins to the northeast; the line of termination for the unit trends northwest. Along the termination, the Yeso Group sand deposits are discontinuous and range in thickness from zero to 3 to 5 m, suggesting a facies change to a more fluvial environment toward the northeast. Up to 20 m thick.

#### **IP-PC** Cutler Group (Pennsylvanian-Permian) We assign the oldest siliciclastic red beds in the Chama Basin to the Cutler Group. Lucas and Krainer (2005) divided Cutler strata into two, mappable lithostratigraphic units, the

El Cobre Canyon and Arroyo del Agua formations. Several lithologic criteria allow the two formations to be distinguished: Contrasting features of the El Cobre Canyon and Arroyo del Agua formations.

Pca Arroyo del Agua Formation (Early Permian) -- Orange siltstone, arkosic sandstone and minor intraformational and extraformational conglomerate. The siltstones are thick, slope-forming units with abundant calcrete nodules between thin sandstone sheets that are arkosic and trough crossbedded. Up to 130 m thick. IPPce El Cobre Canyon Formation (Late Pennsylvanian-Early Permian) Brown siltstone, sandstone and extraformational conglomerate that overlies Proterozoic basement in the subsurface and is conformably overlain by the Arroyo del Agua Formation. Siltstone beds of the El Cobre Canyon Formation contain numerous rhizoliths and comprise relatively thin, slope-forming units between multistoried sandstone beds that are arkosic, micaceous, coarse grained and trough crossbedded. On the Arroyo del Agua quadrangle, upper part contains numerous vertebrate fossils, primarily of Early Permian amphibians and reptiles (e.g., Langston, 1953; Berman, 1993; Lucas et al., 2005c). Up to 90 m thick.

IPgb- Guadalupe Box Formation. (Late Pennsylvanian). Recently defined by Krainer et al. (2005) (=Upper arkosic limestone member of the Madera Group of Northrop and Wood (1946)). Interbedded red to green micaceous, arkosic sandstone, gray sandy, arkosic limestone, gray, fossiliferous, sandy arkosic, cross-bedded limestone, and red, green, and black shale and siltstone. Most common fossils are crinoid columnals. Some arkosic clasts are up to 2 cm in diameter and are angular. Upper contact gradational with clastic red beds of the overlying Cutler Group; lower contact not exposed.





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