Geologic Map of the Arroyo del Agua Quadrangle, Rio Arriba County, New Mexico

By

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Open-file Digital Geologic Map OF-GM 124

Scale 1:24,000

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Geologic Map of the Arroyo del Agua 7.5-Minute Quadrangle, Rio Arriba County, New Mexico

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Introduction

The Mesozoic rocks exposed in the impressive, colorful, 400 m-(1300-foot) high Mesa Alta escarpment, which dominates the landscape in the northern Arroyo del Agua quadrangle (Figure 1), contain a rich, but fragmentary, geologic record spanning approximately 130 million years of Earth's history. Remnants of ancient river systems, vast deserts, saline lakes, broad mudflats, and oceanic shorelines are preserved in the cliffs. Mesa Alta is topped by a gently undulating topography of northeast-trending, narrow finger mesas capped by Cretaceous rocks separated by broad grassy valleys underlain by Jurassic shale at elevations of 2590-2740 m (8500-900 feet) above sea level. South of the escarpment, the northerly-flowing Rio Puerco and easterly-flowing Salitral Creek have incised below the Mesozoic rocks to reveal lucent red, reddish-orange, and white, Permian to Pennsylvanian rocks in the vicinity of the village of Arroyo del Agua (cover photo). Here, an additional ~20- million-year-long record of older river systems, shallow oceans, and sand dune fields is preserved.

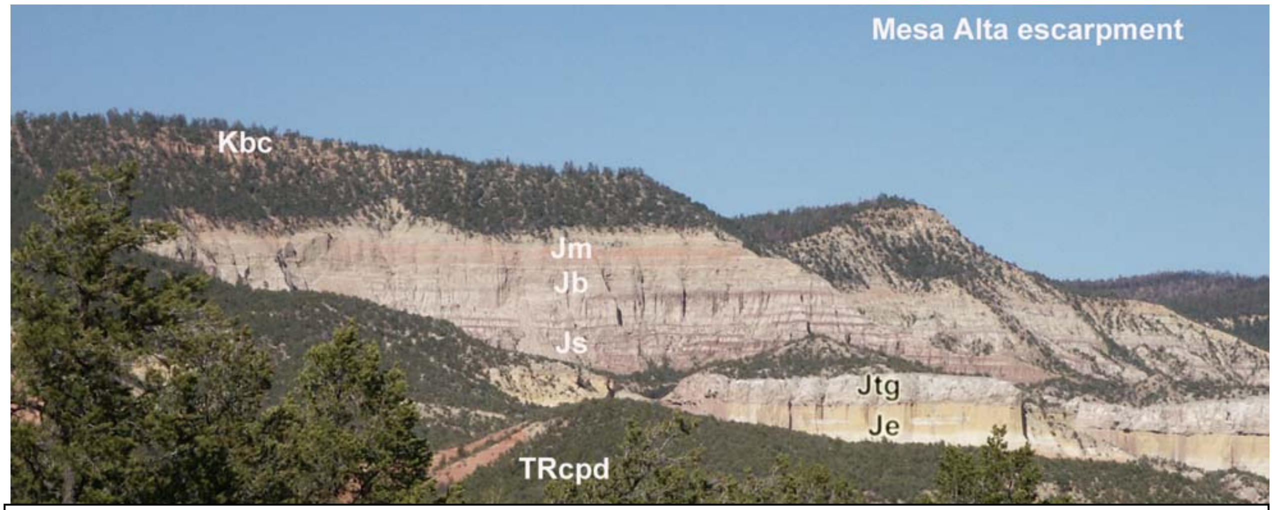


Figure 1. Mesa Alta escarpment in the western part of the quadrangle. TRcpd = Triassic Painted Desert Member, Je = Entrada Sandstone, Jtg is the gypsum facies (Tonque Arroyo Member) in the Todilto Formation, Js= Jurassic Summerville Formation, Jb = Jurassic Bluff Formation, Jm = Morrison Rormation, and Kbc= Cretaceous Burro Canyon Formation.

The Arroyo del Agua 7.5-minute quadrangle lies in the southern Chama Basin, a Laramide-age (~75 to 50 million years old; Cather, 2004) structural basin on the eastern margin of the Colorado Plateau. The area is on the western edge of a broad structural transition zone between extensional faulting associated with the Miocene Rio Grande rift and mildly compressive Laramide deformation associated with the Colorado Plateau; consequently, the latest Pennsylvanian to Cretaceous sedimentary rocks in the quadrangle are moderately deformed by both tectonic events. The Sierra Nacimiento, a Laramide-age uplift, forms the southwestern corner of the quadrangle. Ash flow tuffs derived from eruptions of the Toledo and Valles calderas in the Jemez volcanic field to the southeast of the quadrangle of the cap mesas in the southeastern part of the area.

Previous Work

Wood and Northrop (1946) originally mapped this area at a scale 1:95,040, and the southeastern corner of the quadrangle is included on the 1:125,000 scale geologic map of the Jemez Mountains (Smith et al., 1970). Ridgely (1979) published a preliminary geologic map of the Arroyo del Agua 7.5-minute quadrangle, and she discussed her observations about the regional stratigraphy in the southern Chama Basin in a series of papers (e.g., Ridgely, 1977; 1989). Overall, the Ridgely (1979) map is of good quality. In this study, we offer new detailed mapping of the Arroyo Del Agua quadrangle to augment our understanding of this area.

Significant Contributions

One contribution of this study is a more complete subdivision of the Permian section on the Arroyo del Agua quadrangle. For example, we mapped the De Chelly Sandstone of Yeso Group, which was measured by Eberth and Miall (1991) in the Rio Puerco valley on this quadrangle, and we located its northern termination on Mesa Ojitos and Poleo Mesa. This unit ends along a northwest-trending line, based on exposures on the east side (between UTM coordinates 353840E 4001217N and 353707E 4001501N (NAD27)) and west side (353087E 4001880N) of Ojitos Mesa, and on the north end of Poleo Mesa (350110E 4003040 N). The eolian De Chelly Sandstone is discontinuous and is interbedded with the fluvial sandstone of the Arroyo del Agua Member of the Cutler Formation near the termination, suggesting a facies change rather than an erosion truncation beneath the profound unconformity between the Permian and Triassic rocks. In addition, we mapped the Arroyo del Agua and El Cobre Canyon members of the Cutler Formation separately because the El Cobre Member is a common aquifer target in the southern Chama Basin; documentation of the location, exposed thickness, and structural attitude of the El Cobre Member at the surface may be useful for future subsurface hydrogeologic studies.

Another goal of this mapping study was to identify the members of the Bandelier Tuff (Otowi and Tshirege members) in the southeast corner of the area in order to complete our compilation of an updated geologic map of the Jemez Mountains. Impressive paleovalleys cut on the 1.61 million year old lithic-rich tuff of the Otowi Member that are filled with tuffs of the 1.2 million year old Tshirege Member.

A detailed section of the Cretaceous Burro Canyon and Dakota formations was measured to supplement other detailed sections of older rocks that have been measured on this quadrangle (e.g., Lucas and Krainer, 2005).

Finally, two important field-based observations came out of this work. First, we found that exposures of the basal Triassic units on the underlying Permian units in the Rio Puerco valley are particularly instructive in sorting out the nature and relative timing of pedogenic alteration of these units. Second, the gypsum (Tonque Arroyo Member) and limestone (Luciano Mesa) facies of the Jurassic Todilto Formation were mapped in detail in an effort to refine paleogeographic maps and improve our understanding of the diagenesis of these units. Previously unrecognized sandstone deposits interbedded with the gypsum and a persistent 0.5 to 2 m thick limestone bed capping the gypsum were found during this study. We elaborate on these two observations in the next section.

Paleo-weathered horizon

The top of the Permian De Chelly Sandstone of the Yeso Group beneath the Triassic Shinarump Formation in the Rio Puerco valley is marked by a pronounced weathering horizon; the normally reddish-orange, crossbedded sandstone is bleached to white or yellow and bedding features are obscured. This same paleo-weathering horizon is present beneath the Shinarump Formation on top of the fluvial Arroyo del Agua Member of the Cutler Formation north of the Yeso Group pinchout. The paleo-weathering horizon is not present beneath the thick sandstones of the Shinarump (Agua Zarca) Formation in Cañon de San Diego in the southwestern Jemez Mountains.

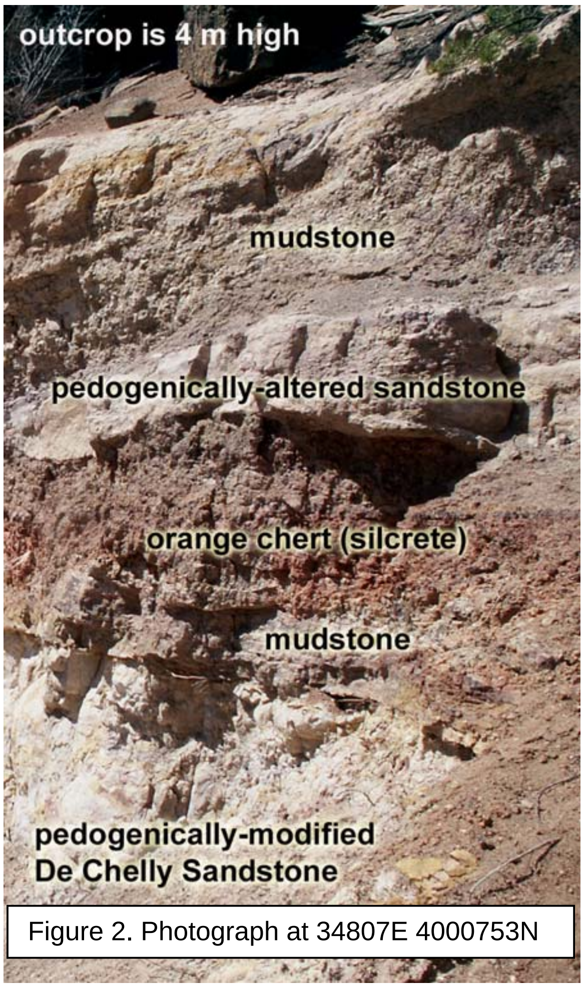
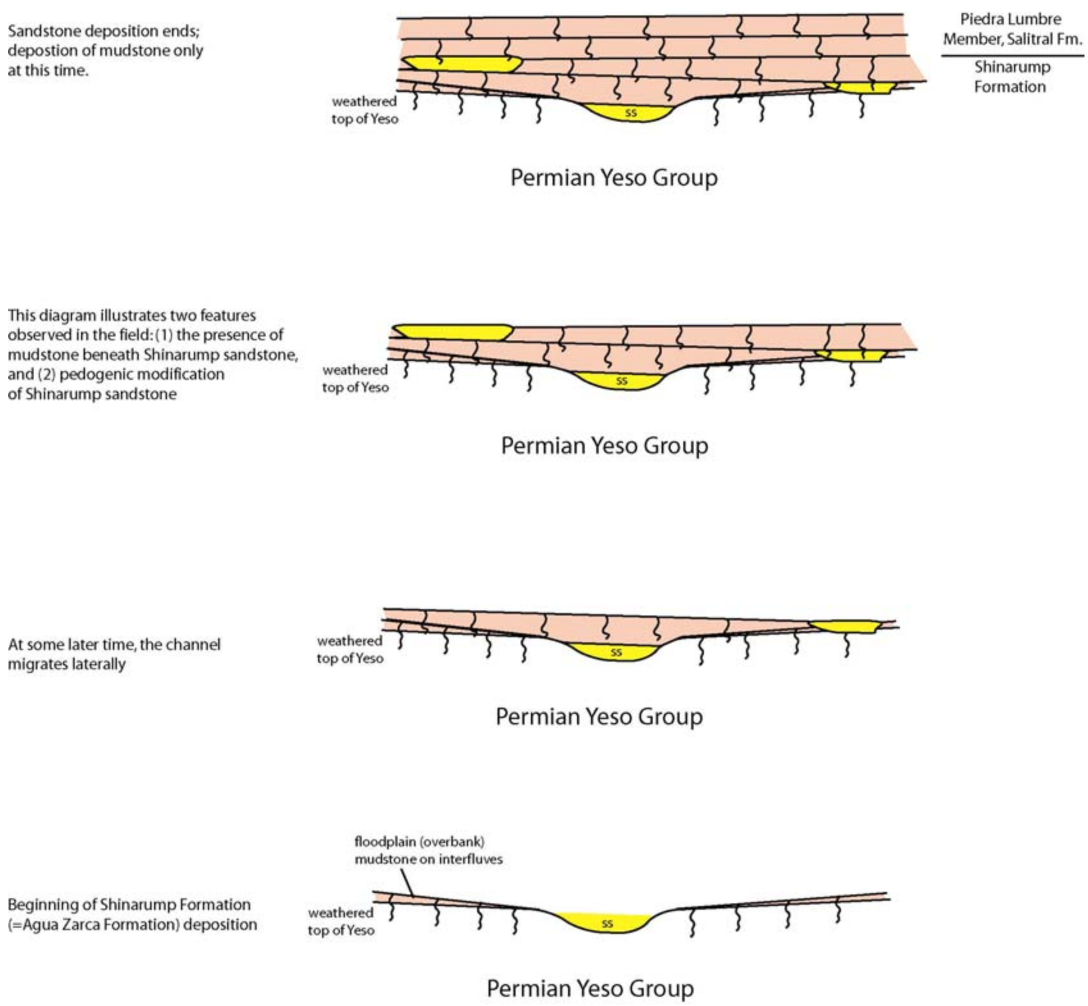


Figure 2. Photograph at 34807E 4000753N

While sandstone of the Triassic Shinarump Formation is usually the basal lithology in the Chinle Group, in many places in the Rio Puerco valley, green, purple, and red smectitic mudstones and siltstones with calcrete nodules interbedded with orange chert beds (<50 cm) are present just above the Permian/Triassic contact (Figure 2). These fine-grained rocks look very similar to the mudstones in the overlying Piedra Lumbre Member of the Salitral Formation. Often, sandstones of Shinarump Formation composition appear in the section 1 to 4 m above the Triassic/Permian contact. Shinarump Formation sandstones, particularly in the lower part of the section, tend to be altered and have purple, red, brown, and orange, hematic staining (Figure 2). Exposure in the Rio Puerco valley is generally good, so that it is possible to trace Shinarump channel sandstones laterally into adjoining mudstone deposits. Alteration of both the Triassic and Permian units is most conspicuous on the interfluves and is virtually absent in places where Shinarump sandstone channels cut deeply into the underlying Permian rocks. Dubiel (1989) noted similar relationships at the Permian/Triassic contact in the vicinity of the village of Coyote just to the east. Dubiel (1989) attributes the pedogenic alteration of the both the sandstone and shale in the Shinarump (Agua Zarca) Formation and the underlying Permian units to fluctuating water tables associated the Shinarump river system. At the time of Shinarump deposition, the area was near about 10° N of the equator, so waterlogged soils on the interfluves, combined with warm mean annual surface temperatures, appear to have led to intense pedogenic alteration of the Permian rocks, the sandstone and mudstone of the Shinarump Formation and the mudstone of the Piedra Lumbre Member of the Salitral Formation (Figure 3). Pedogenic alteration decreased in intensity with the deposition of the overlying El Cerrito sandstone bed and Youngsville Member of the Salitral Formation, perhaps because the soils of these younger units were more well-drained.

Figure 3. Cartoon showing the migration of Shinarump Formation channels through time, with the oldest event at the bottom of the diagram and the youngest at the top. The diagramatic cross-sections are oriented perpendicular to the channel axis; however, most exposures are not oriented perpendicular to the axis, but are more along channel strike, which gives rise to more continuous sand body geometries.



The squiggly lines represent pedogenic modification of the underlying rocks. In places an orange chert (paleo-silcrete) is present in the mudstone.

Paleogeography of the Todilto salina

The Todilto Formation is a fascinating unit that has received much attention over the years because of its economic and scientific importance (e.g., Anderson and Kirkland, 1960, Tanner, 1972, Stapor, 1972, Kirkland et al., 1995). The basal shale and limestone of Luciano Mesa Member is rich in organic matter, and thus is a source rock for petroleum and a host rock for uranium deposits. The upper Tonque Arroyo Member is a source of gypsum for construction material (i.e., sheet rock). The Todilto Formation is thought to have been deposited in a salina or restricted body of marine water (Lucas et al., 1985; Kirkland et al., 1995). Usually makers of geologic maps of the Todilto Formation make no attempt to separate the gypsum from the limestone deposits because the unit is thin and is generally exposed only in sheer cliffs, but we decided to attempt mapping of the separate units both here and on the Ghost Ranch quadrangle (Koning et al., 2006). Figure 4 shows a map of the distribution of four facies that we found during our mapping of these two areas. Our preliminary results are encouraging, and we hope to expand this type of mapping into other parts of the Chama Basin.

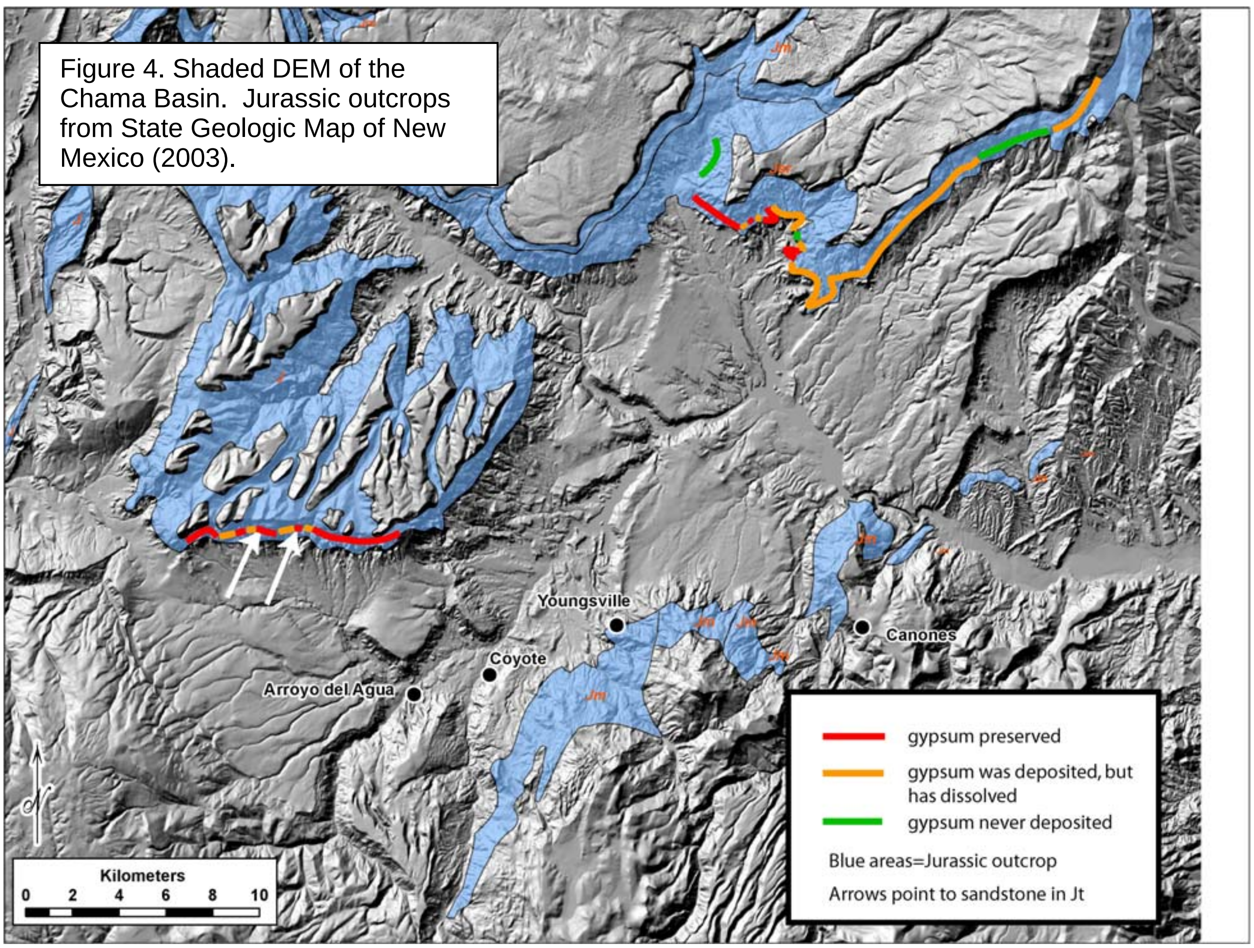
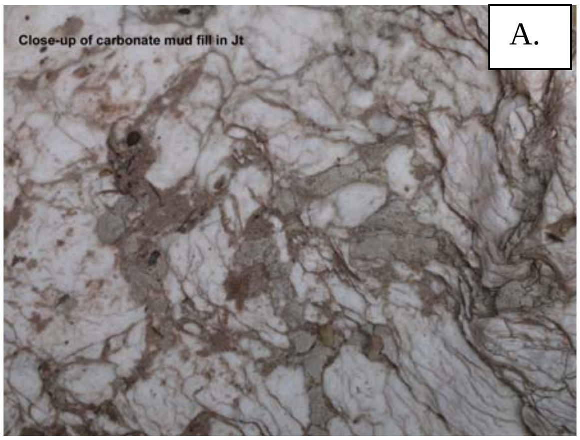
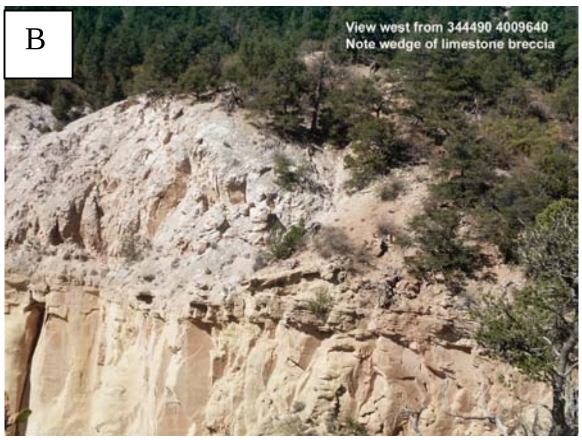


Figure 4. Shaded DEM of the Chama Basin. Jurassic outcrops from State Geologic Map of New Mexico (2003).

We recognize at least five distinct lithologic relationships associated with the Tonque Arroyo Member in the Mesa Alta and Ghost Ranch areas: (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 (e.g., Anderson and Kirkland, 1960); (3) the Tonque Arroyo Member is interbedded with green to red medium-grained quartz sandstone in two places along the Mesa Alta escarpment; (4) the basal sandstone of the Summerville Formation, the Bilk Creek Sandstone Member, rests directly on Mesa Luciano Member; and (5) a thin limestone is present at the top of the gypsum. Thus, Todilto Formation in the southern Chama Basin contains a record of places where gypsum was deposited and is still preserved; areas where the gypsum was deposited, but has since dissolved away; places where the gypsum is interbedded with clastic shoreline deposits; and places where the gypsum was never deposited. The limestone at the top of the gypsum may record a time when the saline water of the salina was diluted, causing a return to carbonate deposition. Units 1 and 2 are present throughout the basin, unit 3 has been observed only on Mesa Alta, and relationship 4 has been documented at Ghost Ranch, but not on Mesa Alta. The limestone of unit 5 is absent in the eastern half of the Ghost Ranch quadrangle; appears discontinuously in the vicinity of the Chimney Rock trail at Ghost Ranch, and is fairly continuous on Mesa Alta. Often the lateral transition between units 1 and 2 (i.e., the places where the gypsum is present and where it is dissolved) is quite abrupt and the overlying Bilk Creek Sandstone dips up to 60° away from the preserved gypsum mound.

A chaotic breccia that contains angular blocks up to 1 m across is often preserved along the contact between the limestone microbreccia and overlying Bilk Creek Sandstone. The breccia can contain blocks of (1) Bilk Creek Sandstone only; (2) blocks of Bilk Creek Sandstone and limestone mircrobreccia; or (3) blocks of Bilk Creek sandstone and the gypsum-capping limestone. This chaotic breccia is very common on the Ghost Ranch quadrangle and relatively rare on Mesa Alta, in large part because the gypsum is more commonly preserved on Mesa Alta compared to the Ghost Ranch area. The chaotic breccia on the Ghost Ranch quadrangle can be associated with narrow, northerly-trending, fluid release features that start in the Todilto Formation and terminate about 5 to 6 m above the Todilto/Summerville contact. The timing of brecciation post-dates lithification of both the Totilto limestone and the Bilk Creek Sandstone, as well as the limestone microbreccia-forming dissolution event. The Bilk Creek Sandstone above the chaotic breccia in areas that are far from preserved gypsum mounds often displays compressional folding and small-scale thrust faulting with displacements on the order of 1 to 2 m. The chaotic sandstone may have formed when gypsum was converted to anhydrite by burial of the area in late Cretaceous time, which released water (gypsum is 38% water by volume; Jowlett et al., 1993). Fluid pressures could have built up at the contact and accommodated compression associated with the early phases of Laramide deformation.





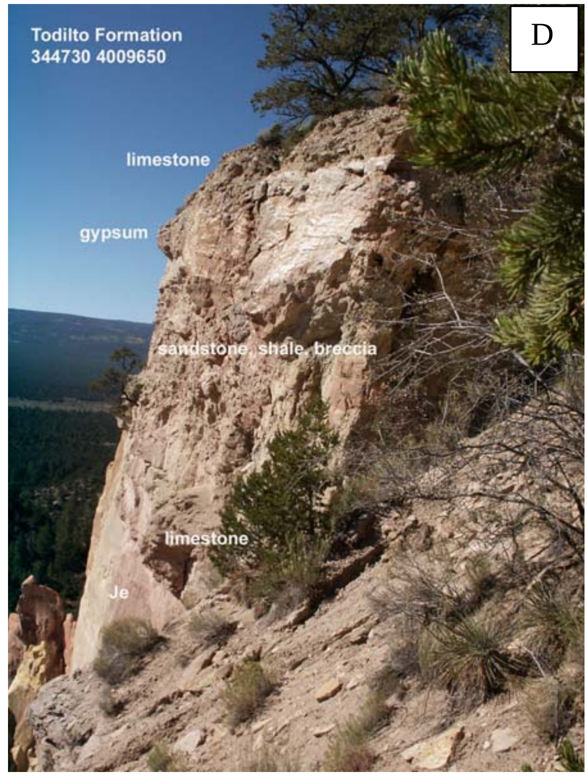


Figure 5. (A.) Carbonate interbedded with gypsum. (B.) Wedge of carbonate microbreccia (composed of residuum of carbonate shown in (A)) juxtaposed against gypsum. (C.) chaotic breccia of Bilk Creek Sandstone blocks between Mesa Luciano limestone and Bilk Creek Sandstone. (D. & E.) Views of sandstone interbedded with gypsum.

Geologic History of the Arroyo del Agua Region

Pennsylvanian

The oldest rocks exposed in the Arroyo del Agua area, located in the southwestern corner of the map area, are interbedded red arkosic sandstone, siltstone, and shale, arkosic sandy limestone, fossiliferous limestone, and black shale that are about 305 million years old. These sedimentary rocks were deposited along the shore of a shallow ocean that once covered the southern two-thirds of the state of New Mexico during late Pennsylvanian time. These rocks were called the arkosic limestone member of the Madera Limestone by Wood and Northrup (1946), but Krainer et al. (2005) have more recently applied the name Guadalupe Box Formation to this interbedded sequence of clastics and carbonates. The arkosic material was likely derived from the Ancestral Rocky Mountain Mountain Peñasco highland (Woodward 1987) located just southwest of the quadrangle, which occupied the current locality of the Sierra Nacimiento.

Latest Pennsylvanian to Permian

Starting about 300 million years ago, the ocean shoreline retreated toward the south, and a south-flowing river system drained the region. The El Cobre Member of Cutler Formation contains abundant cobbles and pebbles of Proterozoic quartzite and granite likely derived from areas to the northeast, off of the Ancestral Rocky Mountain Uncompahgre uplift. As time went on, the climate started to dry out, because channel sandstones in the Arroyo del Agua Member of the Cutler Group are much less common that they are in the older part of the Cutler. The drying trend continued, resulting in the deposition of the sand dunes of the De Chelly Sandstone of the Yeso Group that covered much of northwestern New Mexico and northeastern Arizona about 275 million years ago.

Triassic

Approximately 47 million years of Earth's history are missing at the contact between the Yeso Group and the Chinle Group. The Late Triassic Chinle Group, a thick package of brick-red to red siltstone and mudstone and white to tan sandstone, consists of six distinct rocks units that can be traced around the Chama Basin (Lucas et al., 2005a). These rocks were deposited by rivers between 205 and 228 million years ago, when the Arroyo del Agua area was located about 10° north of the equator. The basal Shinarump Formation (formerly called Agua Zarca Sandstone) is a white to yellow to green, coarse-grained quartz sandstone that locally contains abundant quartzite cobbles; this sandstone is overlain the maroon shales of the Salitral Formation. The Shinarump and Salitral Formations are exposed in the Rio Puerco and Salitral Creek valleys. A second conglomeratic sandstone – mudstone sequence sits on top of the Shinarump/Salitral package. This sequence is composed of the Poleo Formation, a medium-bedded, yellowish-gray micaceous sandstone with conglomertic lenses of siltstone and calcrete clasts, overlain by a thick red to reddish brown mudstone, the Painted Desert Member of the Petrified Forest Formation. In many places, a transitional, thinly-bedded sandstone unit, the Mesa Montosa Member of the Petrified Forest Formation, is present between the Poleo Formation and the Painted Desert Member. The Poleo Formation and Mesa Montosa Member sandstones can be seen along Highway 96 between the Coyote Ranger Station and the western boundary of the quadrangle. Both the Shinarump/Salitral and the Poleo/Petrified Forest sandstone-mudstone packages were deposited by large Mississippi River-scale river systems flowing from central Texas toward the northwest to Nevada. The youngest Chinle Group unit, the Rock Point Formation of Lucas et al. (2005a), is locally exposed in the Mesa Alta escarpment just below the conspicuous red and yellow Entrada Sandstone cliffs. The uppermost unit is a thin-bedded red-brown to gray brown siltstone to sandstone. The world-renowned Whitaker quarry at Ghost Ranch, which contains hundreds of skeletons of an early Triassic dinosaur, *Coelophysis bauri,* is located in this interval (Colbert, 1995).

Jurassic

Another significant gap in the rock record (unconformity) spanning about 44 million years occurs between the late Triassic rocks and the middle Jurassic rocks. The oldest of the middle Jurassic rocks, the Entrada Sandstone, forms the prominent red, yellow, and white cliffs near the base of the Mesa Alta escarpment. The Entrada Sandstone contains spectacular cross-beds that are several feet high, indicating an eolian (wind-blown sand) origin for this unit. The Entrada Sandstone deposits in the Chama Basin are part of a vast sand dune field that covered much of northern New Mexico, southwestern Colorado, southeastern Utah, and northeastern Arizona (Korurek and Dott, 1983; Blakey, 1994; Peterson, 1994). Paleocurrent indicators show that the Entrada sands were transported by wind blowing toward the south to southwest (Tanner, 1965). The Entrada sandstone is estimated to be approximately 161 to 165 million years old.

The Todilto Formation, which consists of a basal limestone and shale unit (Luciano Mesa member) and, in places, 25 to 100 feet of gypsum (Tonque Arroyo member), was deposited on the Entrada Sandstone. A thin bed of limestone commonly sits on the gypsum. The contact between the Entrada Sandstone and the Luciano Mesa limestone member of the Todilto Formation is relatively flat and quite sharp, which has led Ahmed Benan and Kocurek (2000) to speculate that that the Entrada dune field was flooded catastrophically, with very little reworking of the sand dunes. The Todilto Formation was most likely deposited in a salina (Lucas et al., 1985); in other words, in a moderately deep, oxygen-poor, body of saline water that was isolated by a barrier from the main body of the Jurassic ocean located to the northwest, in east-central Utah (Sundance Sea). First, limestone precipitated from the evaporating sea water. Anderson and Kirkland (1960) noted that the basal limestone was deposited in thin layers, with each layer consisting of limestone, clay, and dark organic material. Each layer, or varve, represents a one-year cycle related to seasonal variations in runoff, water temperature, and abundance of lake organisms. Anderson and Kirkland (1960) carefully counted the varves and found that it took 14,000 years for the basal laminated limestone to accumulate. Later, as the saline waters of the salina became more concentrated by evaporation, gypsum precipitated. The Todilto Formation, based on fossil evidence (Lucas et al., 1985), is approximately 159 million years old.

The Todilto Formation grades up into the Summerville Formation. The basal 8-12 m (25 to 40 feet) of the Summerville Formation is laminated white to tan sandstone interbedded with green to red mudstone and shale. Limestone is interbedded with the basal Summerville Formation toward the west. Ripple marks and casts of gypsum crystals are common in the basal Summerville (Bilk Creek) sandstone. The basal sandstone unit is overlain by a thick section of maroon mudstone and pinkish-tan, poorly cemented sandstone deposited on an arid coastal plain (Lucas et al., 1998). Pedogenic carbonate is common in the maroon mudstone, particularly near the top of the unit. The Bluff Sandstone, which is exposed near the top of the Summerville Formation, represents a return to eolian deposition in this area. Cross-beds in the Bluff Sandstone record winds blowing toward the east, suggesting that the Arroyo del Agua area on the North American continent had drifted north into the zone of prevailing westerlies (Lucas and Anderson, 1998).

An unconformity between the Summerville Formation and the overlying Morrison Formation marks a time of a major plate tectonic reorganization of the southwestern United States and a shift from an arid to a more humid environment in this region (Lucas and Anderson, 1998). The Brushy Basin Member of the Morrison Formation, the only member of the Morrison Formation present in the Chama Basin, is made of pistachio-green to salmon-pink mudstone with a few interbedded tan and green sandstone beds. The Morrison Formation was deposited by rivers flowing toward northeast across a broad, fairly low-gradient muddy floodplain that dipped toward the north to northeast away from the developing Mogollon highlands in southwestern New Mexico and southeastern Arizona. Radiometric dating of ash beds ($^{40}Ar/^{39}Ar$ on sanidine; Kowallis et al., 1998) in the Brushy Basin Member in Utah and Colorado yields ages of 148 to 150 million years for this unit.

Cretaceous

The mesas on Mesa Alta are capped by Cretaceous coastal plain, shoreline and marine units that were deposited along the western margin of the Western Interior Seaway ~93 to 125 million years ago. Approximately 25 million years of Earth's history is missing across the contact between the Late Jurassic Morrison Formation and the Early Cretaceous Burro Canyon Formation. The Burro Canyon Formation consists of cross-bedded medium to fine-grained sandstone, quartz and chert pebble conglomerate, and pale-green to pale-red mudstones (Ridgley, 1977; Ridgley 1987; Owen et al., 2005). The unit was deposited by braided streams flowing across a coastal plain towards the northeast to north, toward the Western Interior Seaway. This unit is about 100 to 125 million years old (Owen et al., 2005; Varney, 2005).

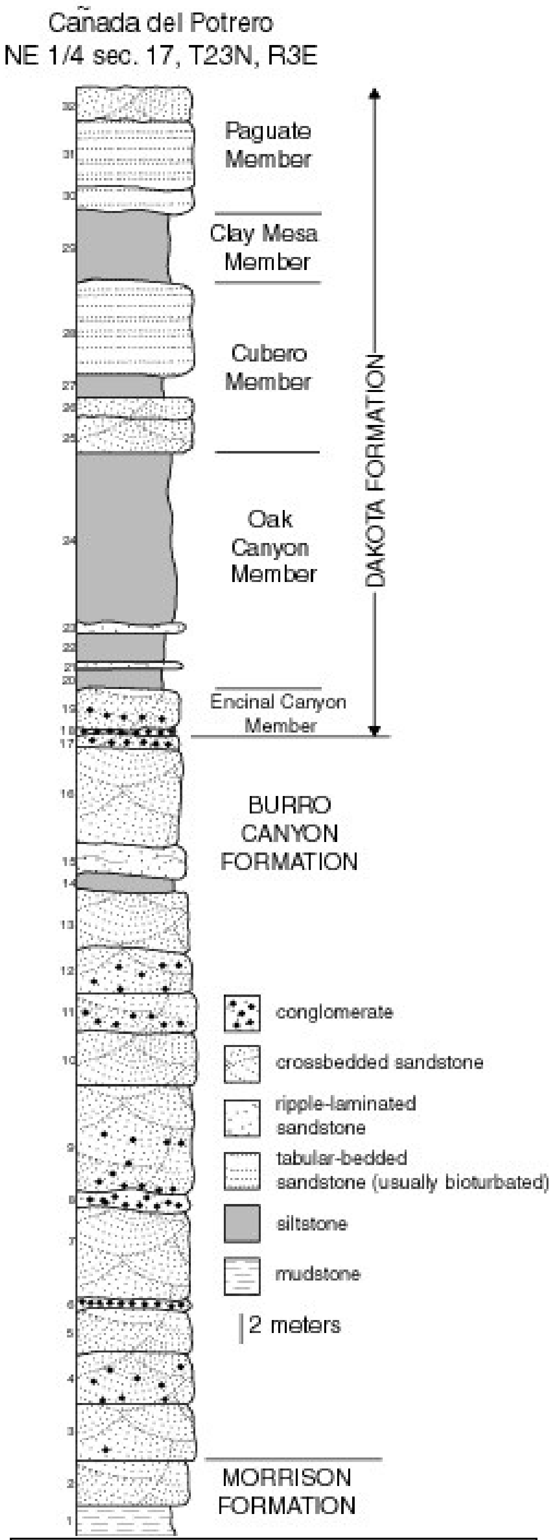


Figure 6. Measured Cretaceous section.

The Dakota Sandstone is composed of interbedded tan- to yellow brown-weathering sandstone and dark gray carbonaceous shale and siltstone. Ripple marks on tops of sandstone beds are common. The sandstones are locally cross-bedded, but, in general, the sandstones were intensely burrowed by marine organisms living in the shallow water along the shores of the Western Interior Seaway. Burrows are structures in sedimentary rocks formed by organisms digging or moving through sediment when the sand or mud was soft; organisms burrow through sediments seeking shelter, protection, or food. The Dakota Sandstone records the alternating rise (shale) and fall (sandstones) of sea level as the shoreline moved back and forth across the area~ 98 to 100 million years ago.

Quaternary

Volcanic activity in the Jemez Mountains to the southeast of the quadrangle blanketed the southeastern part of the area with a thin veneer of ash flow tuff. Tuffs are formed when a highly concentrated cloud of ash, pumice, rock fragments, and gas erupted from a caldera moves downslope. The first large eruption occurred 1.61 million years ago; the tuff filled in a low spot on the east side of the Laramide Sierra Nacimiento uplift. The soft tuff was subsequently eroded, forming steep sided canyons that were subsequently filled by a1.25 million year old tuff.

Later, a thick (10 to 20 m), unconsolidated deposit of old alluvium accumulated in the structural and topographic low that formed between the northward retreating Mesa Alta erosional escarpment and the northern edges of north-dipping Poleo Mesa and Mesa Montosa. The exact age of the deposit is unconstrained. The unit is composed of two facies, a fluvial gravel containing clasts of rounded to subrounded ocal Mesozoic sandstone, limestone and gypsum interbedded with, and in places, overlying fine-grained brown to reddish brown silt. The fluvial facies is overlain by up to 10 m of brown silt with stacked paleosols and interbedded with scattered lenses of gravel. The lower fluvial facies may represent an easterly draining ancestral Salitral Creek that flowed through the east-west- trending topographic low north of Mesa Montosa. Headward erosion by a tributary of the Rio Puerco captured Salitral Creek between monoclines on Poleo Mesa and Mesa Montosa (see below), causing the drainage pattern to assume its modern configuration. The low area north of Mesa Montosa has since been filled with fine-grained pediment deposits to form a south-dipping fan off the Mesa Alta escarpment.

The youngest units exposed on the Arroyo del Agua quadrangle are Quaternary terrace and pediment gravels along the modern drainages, and extensive landslide and colluvial deposits along the escarpment. Many of the terrace gravels in the village of Arroyo del Agua contain Pedernal Chert that is likely derived from Sierra Nacimiento to the south.

Structures

The most prominent structures on the Arroyo del Agua quadrangle are Laramide monoclines that primarily fold sedimentary units older than the Triassic Mesa Montosa Member of the Petrified Forest Formation. Deformation in strata above the Mesa Montosa Member must have been accommodated by the soft shales of the Painted Desert Member of the Petrified Forest Formation; thus the folding in the Jurassic section is subdued or absent. A northwest-trending, northeast-facing monocline on Poleo Mesa and one of similar orientation located in the valley east of Ojitos Mesa parallel the northwest-trending Mesa Pinabetal fault that is exposed in the southwestern corner of the quadrangle. A basement-cored, northwest-trending, northeast-facing monocline is also present just southwest of the fault; the Mesa Pinabetal fault may represent the exhumed roots of a faulted monocline (Kirt Kempter, personal communication, 2006). Two other prominent monoclines, the Mesa Montosa monocline and west edge of the Coyote monocline (Kelley et al., 2005), trend more north-northeast, have larger displacements, and are west-facing. The Mesa Montosa monocline is a faulted monocline along a portion of its length and does propagate in a subdued fashion into the overlying Jurassic rocks.

Faulting on Mesa Alta appears to be limited to two north-trending, down-to-the-east faults and one northeast-trending, down-to-the-west fault. The easternmost normal fault, with a displacement of ~30 m, likely ties into the Coyote Creek fault on the Youngsville quadrangle. This structure is a rift-related fault that has displacements on the order of 60 m in the southern Youngsville quadrangle (Kelley et al., 2005) and 120 m on the Jarosa quadrangle to the south (Timmer, 1976). Several other subvertical structures were observed at the crest of the Mesa Alta escarpment. These have a strike of N10W to N10E and have a minimal vertical displacement of 1 m to10 m of high -angle normal-fault movement, downthrown either to the east or to the west. Minor structures exhibiting slight (1m to 2m) reverse-fault movement also exist. Drag folding of the strata adjacent to such structures is not uncommon. Rarely can these structures be traced for more than a few tens of meters north of the escarpment. However, the general pattern of parallel NNE-trending mesas and drainages suggests apparent structural control on local topography atop Mesa Alta. A prominent system of well developed high-angle joints can be seen intersecting sandstone ledges of the Burro Canyon Formation and Dakota Sandstone along the crest of the Mesa Alta escarpment. Typically, such joints strike NNE (5 to15 degrees NE) and dip steeply (75 to 85 degrees) either to the west or the east.

Economic deposits

Two uranium deposits associated with Todilto limestone on Mesa Alta and in the Cutler Formation on Mesa Montosa were reported by Hilpert (1969). We noted evidence of uranium prospecting at several localities on Mesa Alta at the Morrison/Burro Canyon contact and in the Todilto Formation. The Poleo Formation has been quarried for flagstone on Poleo Mesa.

Geologic Hazards

Landslides are common along the Salitral Formation/ Poleo Formation contact in the Rio Puerco valley. A recent rock fall and a recent landslide were noted (see unit descriptions) in association with this contact.

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