Geologic Map of the Laguna Peak 7.5-Minute Quadrangle, Rio Arriba County, New Mexico

by

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April 2026

New Mexico Bureau of Geology and Mineral Resources
Digital Geologic Map GM 85

Scale 1:24,000

This geologic map was funded in part by the USGS National Cooperative Geologic Mapping Program under STATEMAP award number G23AC00578, 2023. Additional support was made possible by the 2023 and 2024 Technology Enhancement Fund provided by the New Mexico Higher Education Department. Funding is administered by the New Mexico Bureau of Geology and Mineral Resources.

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EXECUTIVE SUMMARY

The Laguna Peak quadrangle is located in the Chama Basin of north-central New Mexico. The Rio Chama cuts across the northeastern corner of the quadrangle. The Rio Gallina, a tributary of the Rio Chama, is located along the northern edge of the quadrangle. For the most part, the Triassic to Cretaceous sedimentary rocks exposed in the area are gently deformed by folding and minor faulting. The Rio Chama has incised a deep, rugged canyon into the relatively flat-lying rocks. Quaternary terrace, piedmont, and landslide deposits record the history of the erosion and aggradation associated with the downcutting of the Rio Chama.

Two discoveries were made during the creation of the geologic map of the Laguna Peak quadrangle. First, a Quaternary travertine deposit covering the surface of one of the younger landslides that encases delicate plant material was found on the north side of Ojitos Canyon. The second discovery was the identification of rounded Quaternary lag gravels that are preserved at an elevation of 2280 m on the south side of the Rio Gallina. This locality is about 280 m above the modern elevation of the Rio Gallina. This deposit contains clasts of Proterozoic quartzite, metaconglomerate, and granite with rounded yellow Mesozoic sandstone clasts that are 1 to 5 cm in diameter.

In addition to finding previously unrecognized Quaternary deposits, two interesting facies trends in the Jurassic Morrison Formation were noted in this area. First, the regional-scale correlation of the maroon, pink, and white sedimentary unit that lies between the top of the Jurassic Todilto Formation and the Westwater Canyon Member of the Morrison Formation has long been the subject of debate. This unit has been variably mapped as the basal Recapture Member of the Morrison Formation or has been tied to the older Summerville and Bluff Formations that are

exposed in Utah. Along the northern edge of the Navajo Peak quadrangle, which lies immediately north of the Laguna Peak quadrangle, the unit in question is composed of pink, stacked channel sandstones with little floodplain material. The character of the unit changes southward across the Navajo Peak quadrangle; the amount of sandstone decreases, and the percentage of red siltstone increases. On the Laguna Peak quadrangle, this unit is predominantly maroon siltstone interbedded with white, poorly cemented sandstone. This north to south facies change may represent a transition from the sandy Salt Wash megafan member of the Morrison Formation to the north and the coeval Recapture floodplain member of the Morrison to the south.

Second, in the region between Ghost Ranch and the village of Gallina in the Chama Basin, the Brushy Basin Member of the Morrison Formation is typically a slope-former composed of green to pink mudstone interbedded with thin sandstones. However, on the north side of Ojitos Canyon, the upper part of the Brushy Basin Member of the Morrison Formation contains stacked cross-bedded sandstone beds that form continuous cliffs that are 6 to 10 m high. These sandstones likely represent a previously unknown channel system in the upper part of the Morrison Formation. The cliffy exposures in Ojitos Canyon also reveal wide channels in the overlying Early Cretaceous Burro Canyon Formation that incise about 10 m down into the Brushy Basin Member.

View of Ojitos Canyon on a rainy evening looking southeast from Mesa los Indios. Sunlight highlights Entrada Sandstone (red, white, and yellow cliffs) capped by white Todilto Formation and maroon Recapture Member of the Morrison Formation. The Entrada Sandstone is underlain by red Painted Desert Member of the Petrified Forest Formation of the Chinle Group.

INTRODUCTION

This report accompanies the *Geologic Map of the Laguna Peak 7.5-minute Quadrangle, Rio Arriba County, New Mexico* (referred to herein as "the map area" or "the quadrangle"). The purpose of this report is to describe, in more detail than is allowable on the map sheet, the depositional environments, stratigraphic relationships, and structural features encountered while mapping. The mapping of this quadrangle is part of a larger project that involves the compilation of the Abiquiu 1:100,000-scale map sheet. An appendix with a full description of map units is presented at the end of this report.

Location and Geologic Setting

The Laguna Peak quadrangle in Rio Arriba County is located about 15 km west of Ghost Ranch and 30 km northwest of Abiquiu, NM. The map area covers the southern portion of the Chama River Canyon Wilderness. Two major drainages cross the map area: the south-flowing Rio Chama and the southeast-flowing Rio Gallina, which is a tributary of the Rio Chama. The floodplain of the Rio Gallina is on private land. Several smaller, intermittent, northeast-trending drainages flow into the Rio Chama, including Cañada de la Presa, Cañada Gurule, and Cañada de los Fuertes. Other prominent landmarks used as references throughout this report include (from north to south) Mesa de los Viejos, Laguna Peak, Mesa Laguna, Mesa los Indios, Mesa Gurule, Mesa Corral, Mesa del Camino, and Mesa Alta (Fig. 1).

This quadrangle encompasses part of the Chama Basin, which is a shallow structural basin that straddles the boundary between the San Juan Basin (west) and the Rio Grande Rift (east). Geologic structures in the Chama Basin formed primarily during compressional Laramide deformation, with some faulting associated with Rio Grande rift extension. The French Mesa portion of the Gallina-Archuleta anticlinorium, a northward extension of the Sierra Nacimiento Laramide highland, lies just within the western boundary of the quadrangle. This structure separates the Chama Basin from the San Juan Basin (Woodward, 1974). Sedimentary bedrock in the map area ranges in age from Triassic to Cretaceous, and records a range of geologic environments, including ancient river systems, vast deserts, saline lakes, broad mudflats, and oceanic shorelines. Quaternary terraces and landslides record a history of incision and aggradation along the Rio Chama corridor.

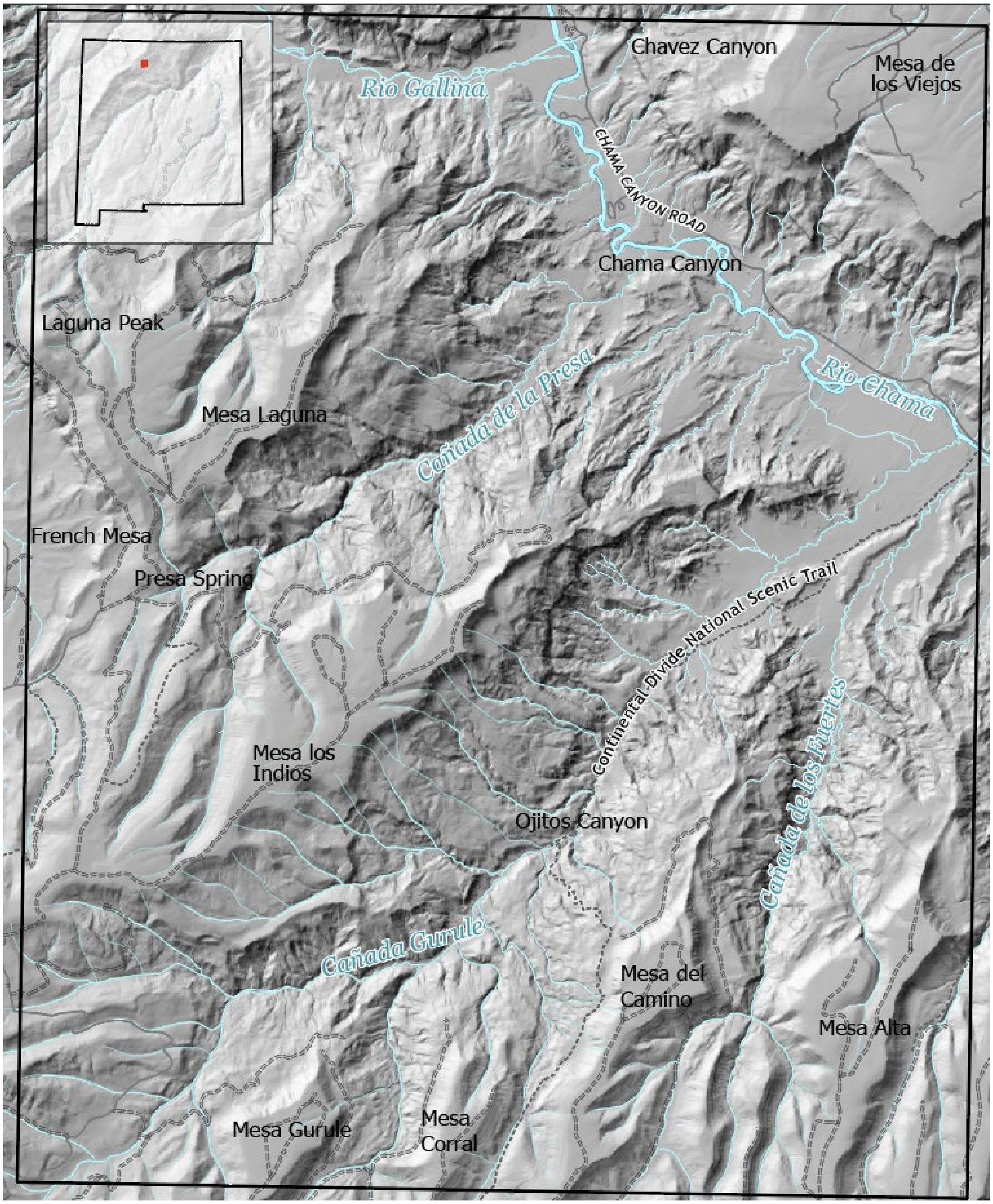


Figure 1. Geographic location map of Laguna Peak quadrangle. Index map in the top left corner of the figure shows the location of the quadrangle (red box). Blue lines are rivers and streams; gray solid and dashed lines are roads and trails.

PREVIOUS WORK

The mapped area is included on the regional-scale geologic maps of Bingler (1968; 1:126,720) and Manley et al. (1987; 1:250,000). Maps of adjoining quadrangles (Smith et al., 1961; Crouse et al., 1992; Kelley et al., 2006; Aby et al., 2016; Aby, 2020; Kelley et al., 2024) were reviewed and taken into account during current mapping. Chesnutt et al. (2019) mapped Quaternary landslides and terraces along the Rio Chama and Rio Gallina south of Mesa Golondrina.

Ridgley and Light (1983) and Ridgley (1983) completed a mineral assessment and an accompanying simplified geologic map (1:48,000) of the Chama River Canyon Wilderness that covers most of the Rio Chama and Gallina Canyon portions of the quadrangle. No economic mineral deposits were found. Sand, gravel, sandstone, limestone and gypsum are the only resources that may have value.

The naming and subdivision of subunits within the stratigraphic interval between the top of the Jurassic Todilto Formation and the base of the Early Cretaceous Burro Canyon Formation has been a matter of some debate. The general stratigraphy above the Todilto includes a series of red to maroon sandstone and siltstone layers, which is, in places, overlain by a discontinuous white cross-bedded sandstone called the Westwater Canyon Member of the Morrison Formation. The uppermost unit in this interval is composed of gray-green mudstones and thin sandstone beds called the Brushy Basin Member of the Morrison Formation. In particular, many names have been applied to the lowest red interval just above the Todilto Formation.

Several authors, including Crouse et al. (1992) on the adjoining French Mesa quadrangle, called the entire interval between the Burro Canyon and Todilto Formations the Morrison Formation. Ridgely and Light (1983) also lumped this interval into a single map unit on their geologic map of the Chama River Canyon Wilderness. Ridgely and Light (1983) label this interval as **Jmw**, which consists of three Morrison members (an unnamed lower member with red sandstone and mudstone, the Westwater Canyon Member, and the Brushy Basin Member), and a new, lowest unit just above the Todilto called the Wanakah Formation that is composed of yellow to white sandstone, black shale, and limestone. The Wanakah is likely related to the Todilto Formation (Lucas et al., 2005) and that name is no longer used.

Lucas et al. (2005) argue that the red interval in the Chama Basin, especially around Ghost Ranch, is not part of the Morrison, and instead they suggest that these rocks resemble the Summerville Formation and the Bluff Sandstone exposed elsewhere on the Colorado Plateau, and these rocks have been mapped as such on quadrangles to the south and southeast. The Westwater Canyon Member is not present at Ghost Ranch. The stratigraphic chart of Lupe (1983) shows that both the Bluff and the Summerville Formations pinch out beneath the San Juan Basin. O'Sullivan (2010) notes that the Summerville Formation is cut out by an unconformity in Utah, so the correlation between rocks in Utah and rocks in north-central New Mexico may not be valid.

In this report, we have chosen to use the stratigraphy outlined in Dickinson (2018; Fig. 2). We use the term Recapture Member of the Morrison Formation for the red unit. Like Ridgley and Light (1983), we recognize a significant facies change from north to south across the Navajo Peak quadrangle immediately north of the Laguna Peak quadrangle in this lowest member of the Morrison Formation. Along the northern boundary of the Navajo Peak quadrangle, the lowest unit is dominated by stacked pink or yellow sandstones with little floodplain material. Sandstone with some mudstone dominates the section down to a latitude that is about 1 km north of Huckbay Canyon on the Navajo Peak quadrangle. South of that point, maroon and red floodplain mudstone is intercalated about equally with white and red sandstone. We speculate that the sandstone dominated section might be part of the southern edge of the Salt Wash Sandstone lobe of Dickinson (2018). Dickinson (2018) notes that the Salt Wash megafan grades laterally southward into the Recapture Member (Fig. 3). In the Laguna Peak quadrangle, most outcrops are dominated by red mudstone and weakly cemented white sandstone. An exception is noted on the south side of Mesa los Indios, where this unit is predominantly cross-bedded, poorly cemented white sandstone with little mudstone.

Most recently, Chestnutt et al. (2019) mapped about 15 km along the Chama Canyon corridor between the southern Navajo Peak quadrangle to the middle of the Echo Amphitheater quadrangle from the canyon rim down to the river. Their study focused on characterizing landscape evolution related to Rio Chama incision using detailed landslide and terrace mapping and geochronology.

Chestnutt et al. (2019) reported four valid radiocarbon dates from Rio Chama terraces. Two of the dated terraces are overlain by landslide deposits and provide maximum ages for those landslides: ≈32.6 ka for **Qlso** and ≈22 ka for **Qlsi**. The authors also determined an average Rio Chama incision rate of 500 m/Myr in the last 40,000 years, with a minimum rate of 90 m/Myr in the last 3.4 million years.

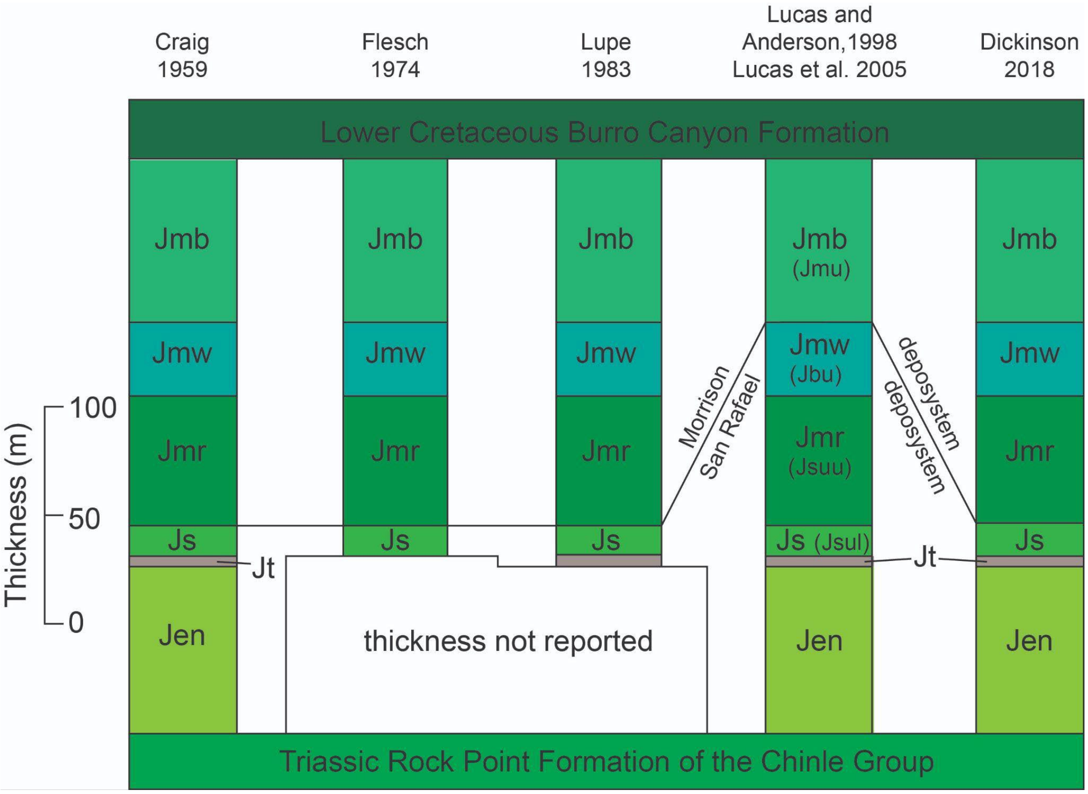


Figure 2. Correlation chart for the Jurassic section exposed at Ghost Ranch, which is located about 15 km east of the quadrangle (modified from Dickinson, 2018). The abbreviations in parentheses are based on the terminology used by Lucas and Anderson (1998). Jen=Jurassic Entrada Sandstone; Jt=Todilto Formation, Js=Summerville Formation; Jsul=lower Summerville Formation; Jsuu=upper Summerville Formation; Jmr=Recapture Member, Morrison Formation, Jmw=Westwater Canyon Member, Morrison Formation; Jbu=Bluff Sandstone; Jmu=undifferentiated Morrison; Jmb=Brushy Basin Member, Morrison Formation.

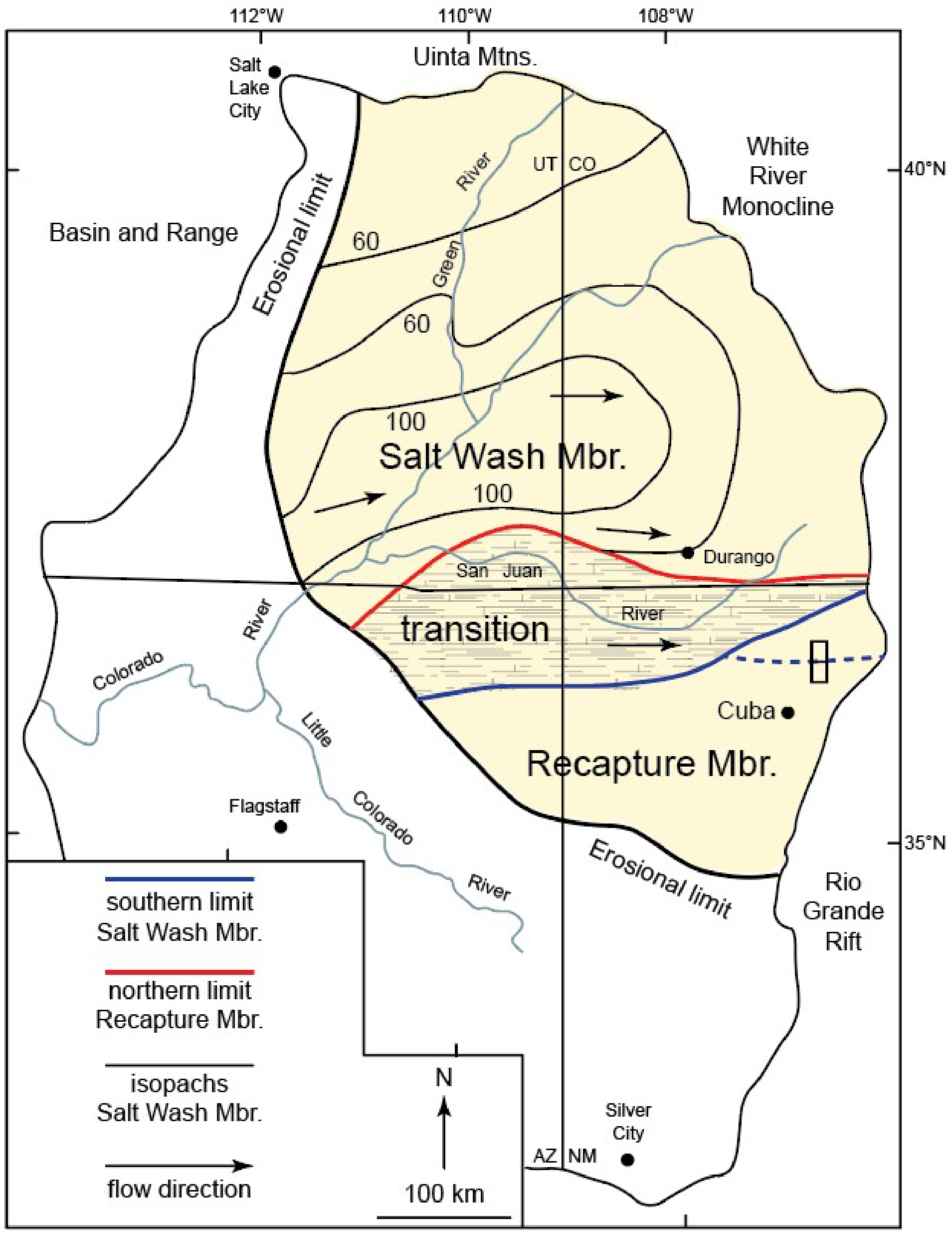


Figure 3. Paleogeographic reconstruction of the depositional environments during early Morrison time (modified from Dickinson, 2018). The black rectangle shows the location of our study area (Navajo Peak [top] and Laguna Peak [bottom] quadrangles) and the blue dashed line shows the proposed adjustment of the southern limit of the transition between the Salt Wash and Recapture Members based on our observations.

MAPPING METHODS

The Burro Canyon Formation and the Entrada Sandstone cliffs are major obstacles to accessing the Chama River Canyon Wilderness on foot within much of the quadrangle, so we used rafts to map the main river corridor. Otherwise, we walked down landslides or colluvial slopes. We used field observations, aerial imagery, and lidar to identify the units described in this report. Aerial photographs were collected by the National Agriculture Imagery Program in May 2022. In the field, locations of geologic point data were primarily obtained using a handheld GPS unit or by referring the available topographic maps. Contacts and faults were drawn onto base maps that showed topography using contour lines and Lidar hill-shade maps. All geologic data gathered in the field were then transferred to ArcGIS Pro 3.3.1 for digitization.

GEOLOGIC HISTORY

Detailed descriptions of the rock units exposed in the Laguna Peak 7.5-minute quadrangle are presented in the appendix at the end of the report.

Triassic

The oldest exposed rocks in the quadrangle are part of the Triassic Chinle Group, which were deposited between approximately 230 and 200 Ma (Lucas and Spielman, 2013) by Mississippi River-scale fluvial systems that flowed from what is now central Texas toward what is now northwest Nevada (Stewart et al., 1972). The very top of the Poleo Formation (unit **TRcl**) is the oldest Chinle Group formation exposed in the map area; this unit consists of pebble conglomerates, quartzose sandstones, and mudstones. The Poleo Formation grades up into the transitional, discontinuous, thinly bedded sandstones of the Mesa Montosa Member of the

Petrified Forest Formation. These two units are exposed along the banks of the Rio Chama, below the confluence of the Rio Chama and the Rio Gallina. The Mesa Montosa Member is overlain by the thick, red to reddish-brown mudstone of the Painted Desert Member of the Petrified Forest Formation and the brick-red Rock Point Formation (Fig. 4). The Painted Desert Member is composed primarily of floodplain mudstone and siltstone with occasional sandy channel deposits. The Rock Point Formation (Lucas et al., 2005) is the youngest unit within the Chinle Group and contains primarily red, silty/sandy levee and floodplain deposits (Fig. 5). The Rock Point Formation and the Painted Desert Member of the Petrified Forest Formation are shown on the geologic map as a combined upper Chinle Group map unit (TRcu).

Figure 4. View from Laguna Mesa looking southeast toward Mesa de los Viejos across the Rio Chama valley. The floor of the valley is underlain by the Painted Desert Member of the Petrified Forest Formation of the Chinle Group.

Figure 5. Ledgy, brick-red Rock Point Formation below red Entrada Sandstone on the southwest side of Mesa de los Viejos.

Jurassic

Following deposition of the Chinle Group sediments, the map area experienced a period of non-deposition or erosion until the early Callovian stage of the Middle Jurassic, when the San Rafael Group was deposited (Imlay, 1980; Lucas et al., 1985). The San Rafael Group includes the Entrada Sandstone and the Todilto Formation in the Chama basin. The Entrada Sandstone forms prominent red, yellow, and white cliffs along the Rio Chama and its tributaries (Fig. 6). Spectacular, meters-high cross-beds indicate an eolian (windblown) origin for this unit and suggest that the Entrada Sandstone was deposited as part of a vast dune field throughout what is now 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).

Cliffs of the Entrada Sandstone are capped by the Todilto Formation (Fig. 7), which consists of a basal limestone unit (the Luciano Mesa Member) and, in places, up to 60 m of gypsum (the Tonque Arroyo Member). The Todilto Formation was likely deposited in hypersaline water that was separated from the Jurassic Sundance Sea, which was located in what is now east-central Utah (Kirkland et al., 1995). The contact between the Entrada Sandstone and the Luciano Mesa Member of the Todilto Formation is sharp and relatively flat, which may suggest catastrophic flooding of the Entrada dune field with little reworking of the Entrada sands (Ahmed Benan and Kocurek, 2000). The Luciano Mesa Member was deposited as thin layers of kerogenic limestone and shale. As evaporation within the closed Todilto basin continued, the system transitioned from deposition of limestone to deposition of alternating layers of gypsum and limestone. Fossil evidence suggests that the Todilto Formation was deposited during the early to middle Callovian (Lucas et al., 1985).

Figure 6. Exposure of the Entrada Sandstone along the west side of Mesa de los Viejos. Note the large-scale cross-beds. Here, the Entrada is overlain by the limestone-dominated Luciano Mesa Member of the Todilto Formation.

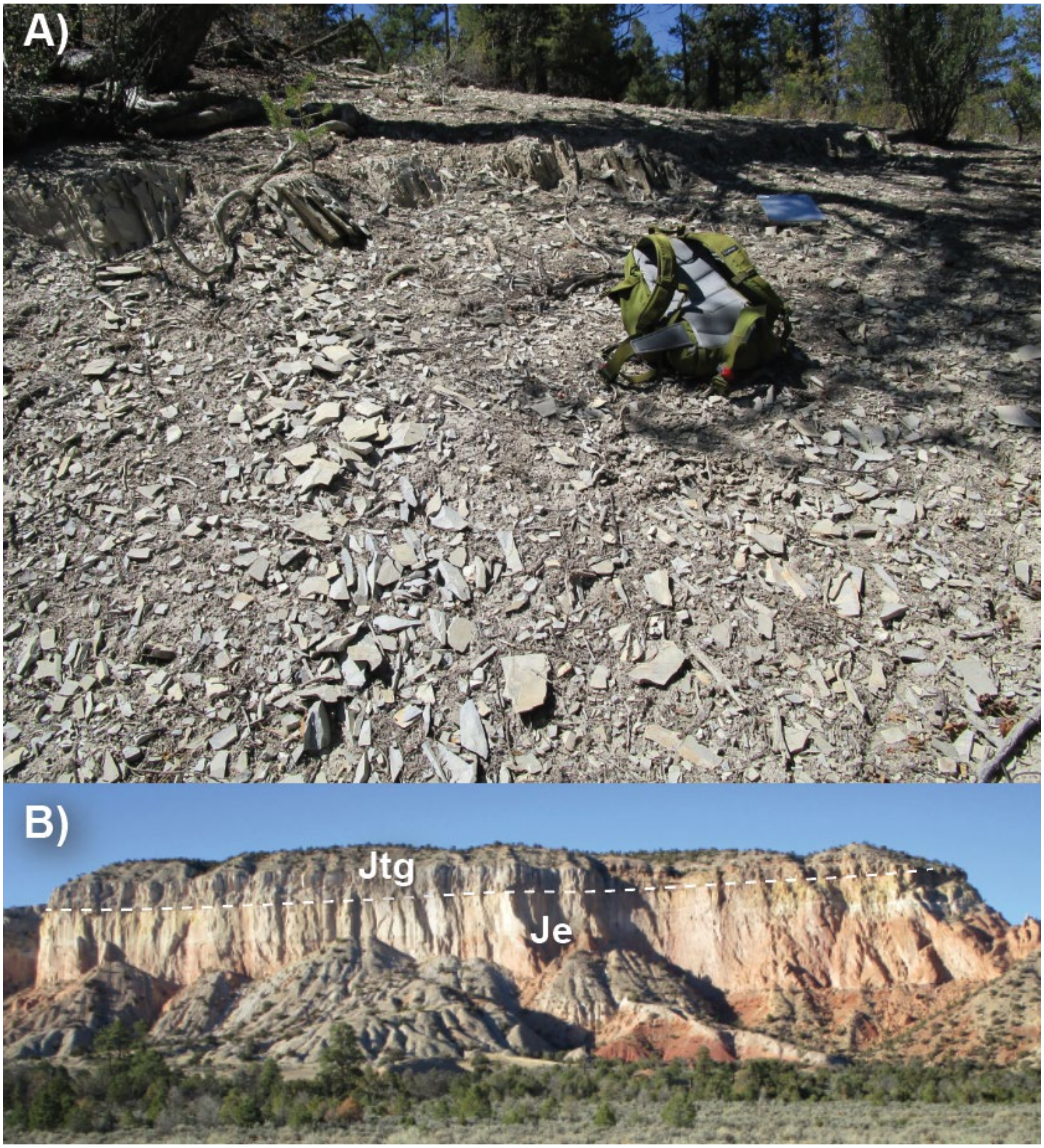


Figure 7. A) Weathered fragments of limestone of the Luciana Mesa Member of the Todilto Formation; this member is lumped with the Entrada Sandstone when the gypsiferous Tonque Arroyo Member of the Todilto is not present. Photo taken on the cliffs just south of Laguna Peak. B) Annotated photograph showing the contact between cliffs of the Entrada Sandstone (**Je**)

and the overlying Todilto Formation (**Jtg**). Unit **Jtg** is mapped here as a separate unit because the gypsiferous Tonque Arroyo Member is present. Photo taken in Ojitos Canyon.

Deposition of the 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 climate in this region (Lucas and Anderson, 1998). At the start of Morrison deposition, the area that is now northwestern New Mexico was at latitudes between 35° and 38°N, which produced arid conditions and contributed to some eolian deposition in the Recapture Member (Dickenson, 2018). In the Laguna Peak quadrangle, the Recapture Member is dominated by red, floodplain mudstone and weakly cemented, white sandstone (Fig. 8 and 9). Later, the Westwater Canyon and Brushy Basin Members were deposited in more humid conditions at latitudes between 45° and 48° (Dickenson, 2018). At this time, rivers flowed northeast across a muddy floodplain and away from the developing Mogollon rift-flank and arc-related highlands in what is now southwestern New Mexico and southern Arizona. The Westwater Canyon Member is a white, trough cross-bedded, channel sandstone that is discontinuously preserved across the quadrangle (Fig. 10). The Westwater Canyon Member is overlain by the Brushy Basin Member, which generally consists of pistachio-green and reddish-pink mudstone with interbedded tan sandstone beds (Fig. 11 and 12a). In Ojitos Canyon, stacked, cross-bedded sandstone beds forming cliffs 6–10 m high are common near the top of the Brushy Basin Formation. Sanidine ^{40}Ar/^{39} Ar dating of ash beds in the Brushy Basin Member in Utah and Colorado yields ages of 152.2 ± 0.3 Ma to 150.0 ± 0.5 Ma at the bottom and top of the section, respectively (Kowallis et al., 1998; recalculated with new age constraints from Kuiper et al., 2008). Because of the abundance of soft mudstones in both the Recapture and Brushy Basin Members, most of the Quaternary landslide failures originate from these units within the map area.

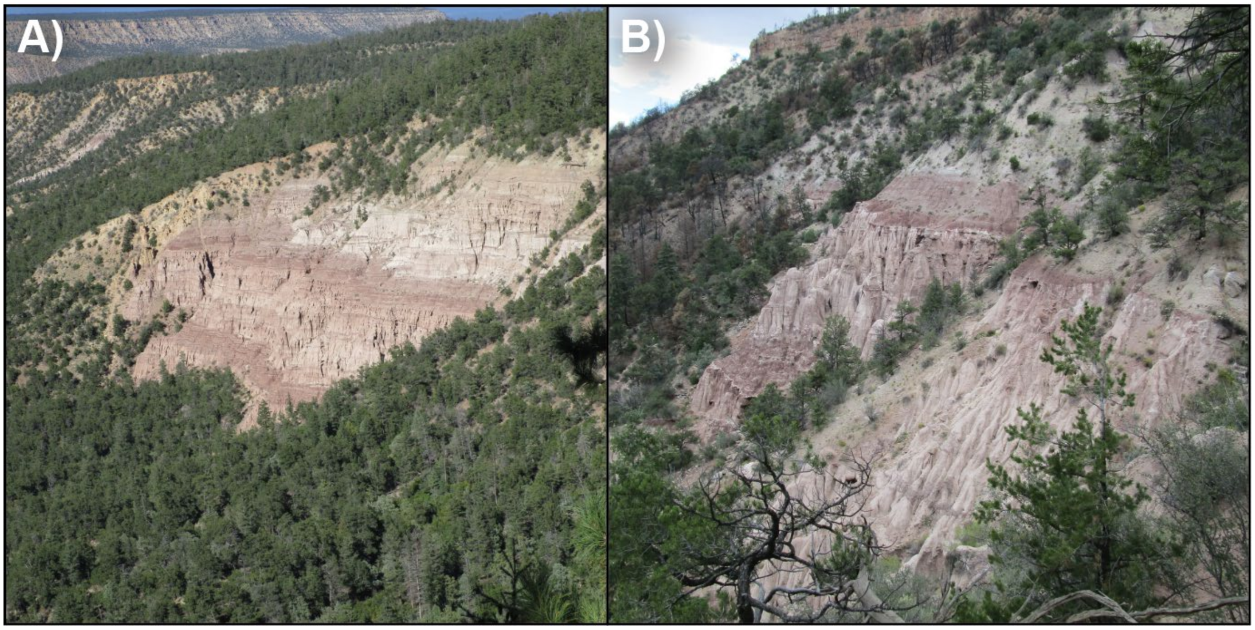


Figure 8. A) Recapture Member in Cañada de los Fuertes. B) Recapture Member overlain by Brushy Basin Member in Ojitos Canyon.

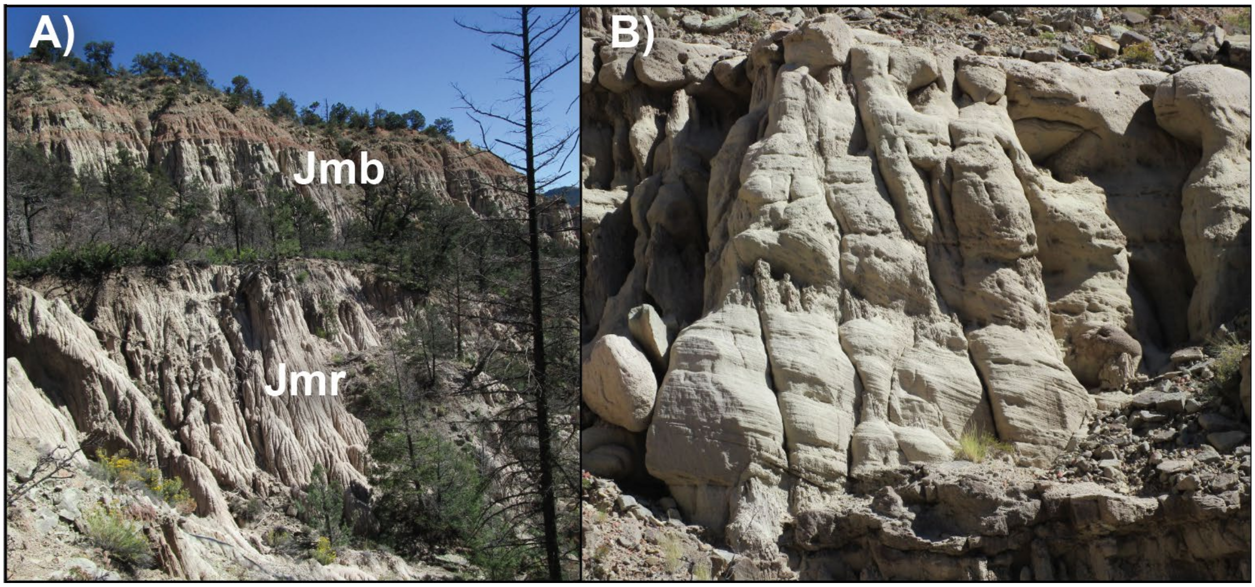


Figure 9. A) An unusual deposit of poorly cemented sandstone with little maroon siltstone in the Recapture Member (Jmr) below Brushy Basin Member (Jmb) on the south side of Mesa los Indios. B) Close-up of the cross-beds in this unusual deposit; photo looking northeast.

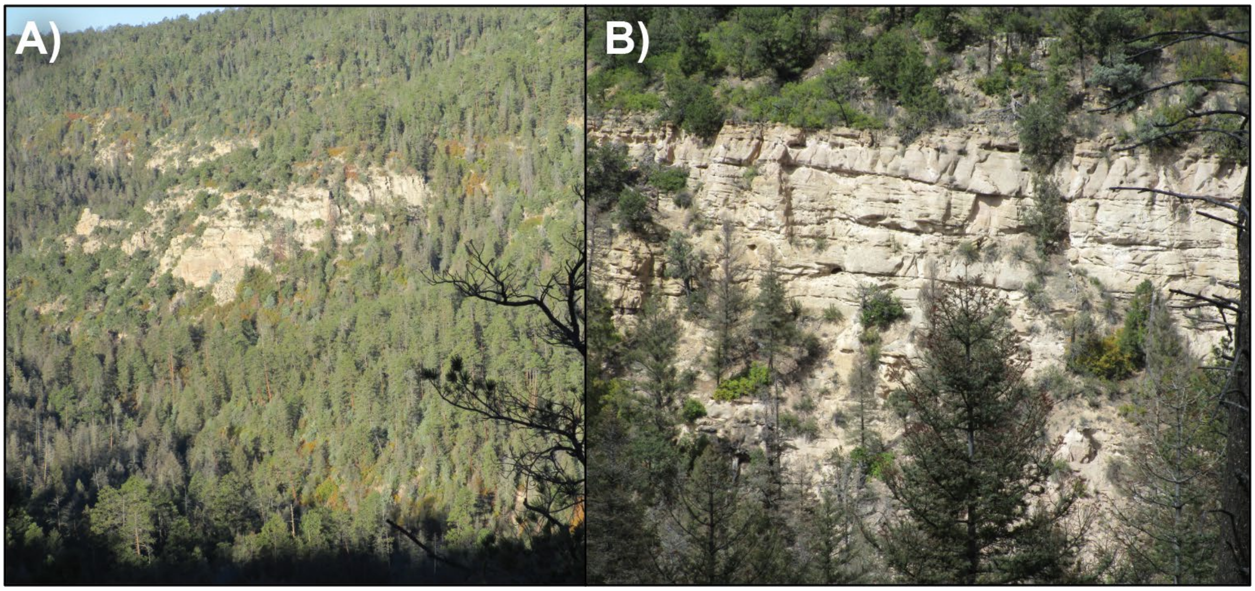
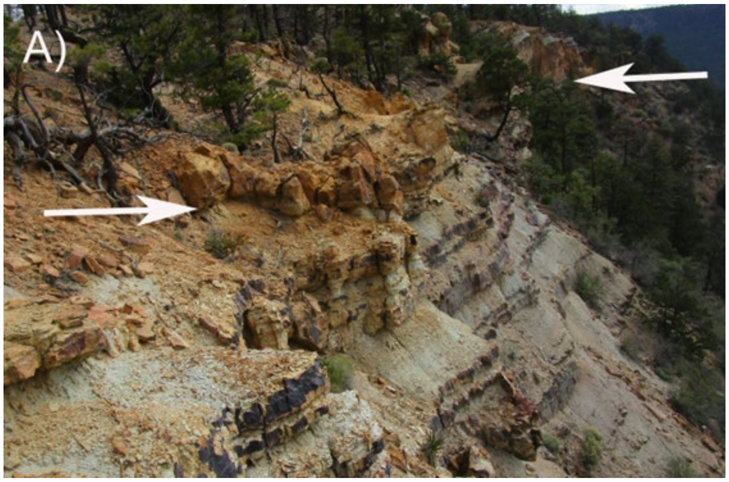


Figure 10. A) A view of an isolated outcrop of the Westwater Canyon Member looking north up Presas Canyon. B) Closeup view of the Westwater Canyon Member near Presas Spring.

Figure 11. Brushy Basin Member atop the Recapture Member of the Morrison Formation in Cañada de los Fuertes.

Cretaceous

The map area underwent an approximately 25-million-year period of non-deposition or erosion between deposition of the Brushy Basin Member of the Morrison Formation and the Early Cretaceous Burro Canyon Formation (Fig. 12b; Saucier, 1974). The Burro Canyon Formation consists of cross-bedded, medium- to fine-grained sandstone, quartz and chert pebble conglomerate interbedded with pale-green to pale-red mudstones (Ridgley, 1977; Ridgley, 1987; Owen et al., 2005). The unit was deposited by braided streams flowing north and northeast from the Mogollon highlands toward the Western Interior Seaway (Owen et al., 2005). Palynomorphs from the Burro Canyon Formation in western Colorado suggest deposition began in the Aptian (possibly as early as the Barremian) and continued through the early Albian (Tschudy et al., 1984). A study by Milàn et al. (2015) reports a detrital zircon, maximum depositional age of ~130 Ma for the lower Burro Canyon Formation in southeastern Utah. As such, we interpret a 125–110 Ma age for the unit.



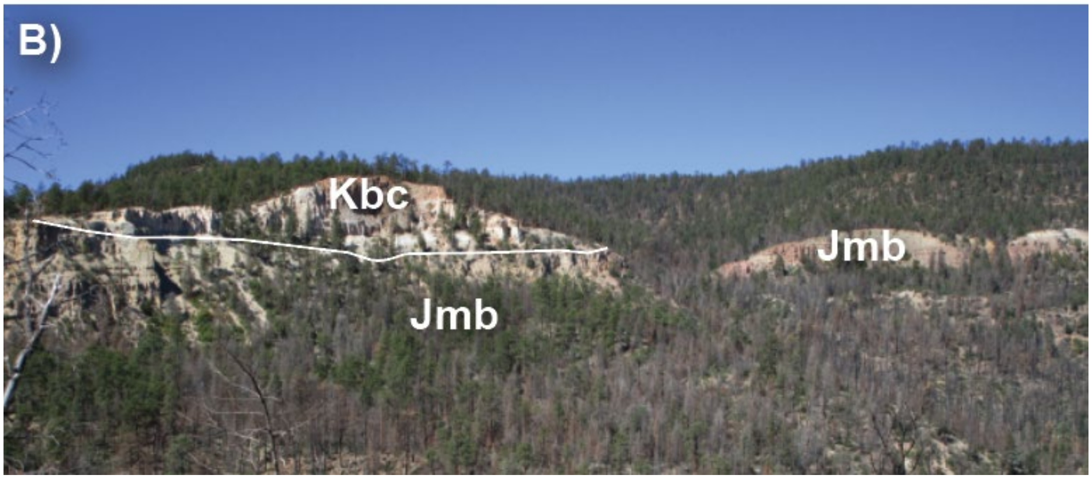


Figure 12. Two outcrops between Ojitos Canyon (Fig. 12a) and the top of Mesa los Indios (Fig.12b.), on the south side of the mesa, expose thick Burro Canyon Formation channels that incised about 10 m into the underlying Brushy Basin Member of the Morrison Formation. The arrows in Fig. 12a and the white line in Fig. 12b mark the contact between the units. The Brushy Basin Member forms cliffs in this area because the unit contains more sandstone beds than usual.

The overlying Dakota Sandstone and interbedded Mancos Shale consist of tan to yellow-brown sandstone and dark-gray carbonaceous shale and siltstone; these units represent an overall marine transgression (relative sea-level rise) and expansion of the Western Interior Seaway (Varney, 2005). The lowest member, the Encinal Canyon Member of the Dakota Sandstone (Fig. 13), represents a transition from terrestrial facies to shallow, tide-dominated and open-marine, wave-dominated marine environments (Varney, 2005). The Cubero Tongue and Paguate Tongue sandstone outcrops are locally cross-bedded and commonly bioturbated. Both the Clay Mesa Tongue of the Mancos Shale and the Paguate Member of the Dakota Sandstone thin southward in the Rio Chama region (Owen et al., 2005). The Dakota Sandstone is generally regarded as Cenomanian (Owen et al., 2005). Varney (2005) reports an approximately 93 Ma age for the middle of the upper part of the unit in the Chama Basin, and Dyman et al. (2002) report an approximately 95 Ma age for the middle of the lower part of the unit in southeastern Utah. Both $^{40}Ar/^{39}Ar$ dates are from sanidine in interbedded bentonite layers. We interpret the Dakota Sandstone to be between about 98 and 93 Ma in the map area.

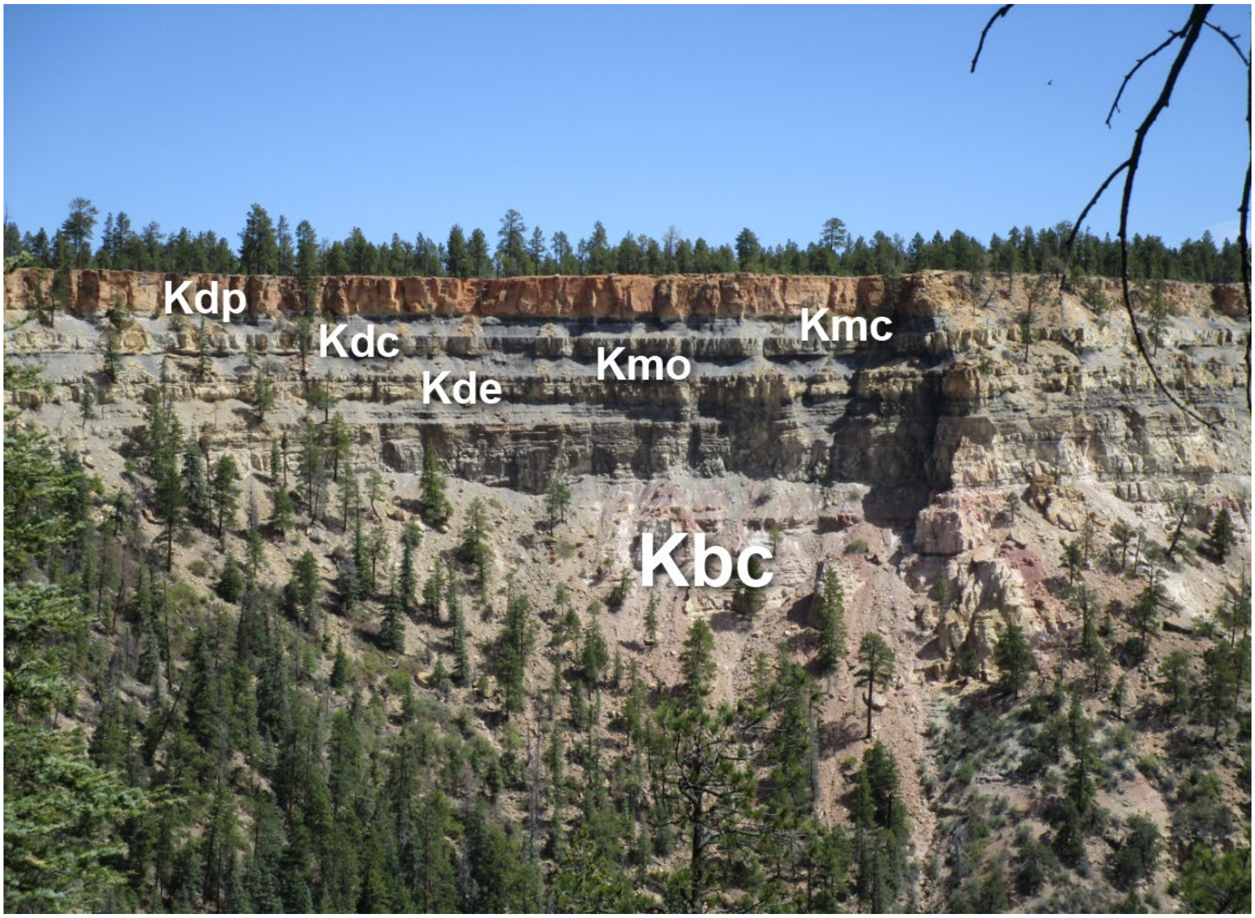


Figure 13. Great exposure of 1) Encinal Canyon Member, 2) Oak Canyon Member, 3) Cubero Tongue, 4) Clay Mesa Tongue, and 5) Paguate Tongue of the Dakota Sandstone and Mancos Shale (**Kd**) overlying the Burro Canyon Formation (**Kbc**) on the south side of Laguna Mesa.

Neogene and Quaternary

The Neogene and Quaternary deposits that are preserved in the map area are related to the formation and incision of the Rio Chama and its tributaries. Based on exposures in the northern Jemez Mountains, an ancestral Rio Chama was established by at least 8 Ma (Kelley et al., 2013) and reached its current configuration by 1.2 Ma (Repasch et al., 2017). The Rio Chama-Rio Grande system transitioned to an incisional regime after 1 Ma, wherein magmatic, tectonic, and climatic perturbations facilitated regional downcutting (Repasch et al., 2017).

Rio Chama and Rio Gallina terraces preserved in the map area record short periods of stability during a period of overall incision. Chesnutt et al. (2019) recognized six Rio Chama terraces and six tributary terraces during his study of the evolution of the landscape in this area; we have chosen to map the tributary terraces of Chesnutt et al. (2019) as alluvial fan deposits. The Rio Chama terraces primarily contain well-rounded Proterozoic quartzite and intermediate to basaltic volcanic cobbles and pebbles, with trace granite, meta-rhyolite and chert clasts. The Rio Chama terraces also contain a variable but subordinate amount of Mesozoic sandstone clasts, particularly immediately downstream of sandstone outcrops. In contrast, the fan deposits are usually composed of red, tan, and brown, fine-grained sand and silt with sparse to common pebbles and sparse cobbles of rounded to angular sandstone and gypsum.

Our mapping of terraces along the Rio Chama canyon was informed by previous mapping from Chestnutt et al. (2019; 1:24,000), as well as new mapping. Rio Chama terraces 2 and 3 of Chestnutt et al. (2019) are preserved downstream of the Laguna Peak quadrangle and are not present in the map area. We map three Rio Chama terraces, which are outlined in Table 1.

Table 1. Terrace tread heights and ages in the Laguna Peak quadrangle

This map	Approximate height range	Median calibrated ^{14}C age (yr BP)*
Qtch1	<10 m	966 yr BP
Qtch2	15-25 m	34,603 yr BP
Qtch3	25-40 m	40,865 yr BP

* yr BP = years before present; ages from Chestnutt et al. (2019)

Rio Chama channel terraces are preserved south of the confluence and north of the mouth of Ojitos Canyon. Radiocarbon dates on shells preserved in units **Qtch2** and **Qtch3** are 35,513 – 34,003 yr BP and 41,408–40,339 yr BP, respectively (Chesnutt et al., 2019). Unit **Qtch1** yielded a radiocarbon date on charcoal of 939–1,017 yr BP (Chestnutt et al., 2019).

We differentiate three alluvial deposits along the Rio Gallina based on the average height of the deposit above modern river grade, which we correlate to a relative age designation: **Qao**, **Qai**, and **Qay**. We did not map this alluvium as terraces because we were not able to field check the deposits due to time constraints.

In this map, we rename the tributary terraces of Chestnutt et al. (2019) as alluvial fans. This distinction is made for semantic preference, as the tributary terraces of Chestnutt et al. (2019) were likely deposited by tributary alluvial fans. Regardless of the name used, these deposits consist of cobbles and boulders of locally sourced, Mesozoic sandstone and siltstone. Figure 14 shows an example of one of these fan deposits along the eastern edge of the quadrangle.

Large scale mass-wasting events, including earth flows, translational and rotational slides, slump blocks, and debris flows are also preserved in the map area, and represent the response of the canyon to rapid incision and oversteepening. Of particular interest is a relatively intact slump block composed of Jurassic Entrada Sandstone and overlying Todilto Formation and Recapture Member of the Morrison Formation that is back-rotated 50° to the southwest (Fig. 15a) and is located about 2 km from outcrops in the current wall of the canyon (Fig. 15b). Chestnutt et al. (2019) suggest that slump blocks such as this one may have been "rafted" by later landslide events.

We generally followed the landslide mapping of Chestnutt et al. (2019), particularly in the Rio Chama corridor, but we added or modified features based on field observations and interpretations from lidar. We aimed to preserve the landslide naming schema of Chestnutt et al. (2019) and applied their relative age criteria to landslides we mapped in the southern portion of the map area. Where crosscutting relationships and surface roughness were insufficient for determining relative age, we mapped landslides as **Qls** (undifferentiated). We lump Chestnutt's "undifferentiated slide blocks" into our unit **Qc**.

One of the youngest units in the map area is a travertine deposited on top of a landslide at the base of Entrada Sandstone cliffs in Ojitos Canyon. The travertine appears to have been deposited by a paleospring that formed at the contact between the Entrada Sandstone and the underlying fine-grained deposits of the Rock Point Formation in the Chinle Group. The base of the Entrada is brecciated and the breccia is cemented with calcium carbonate. The paleospring waters apparently flowed downslope across a Quaternary landslide deposit. The preserved base of the travertine is about 24 m below the base of the Entrada cliffs and about 8–10 m above the base of the landslide. The base of the travertine exposure is about 20 m above Ojitos Creek. The travertine deposit encased plant material, preserving delicate twigs and possible flower buds in detail (Fig. 16).

Figure 14. An alluvial fan deposit on the east side of the Rio Chama (353747E, 4022635N, NAD83). Sandy silt with scattered round pebble gravel (< 3%) forms the basal unit; the indurated unit on top is a boulder conglomerate cemented by calcite that forms thick rinds around the clasts (old paleospring deposit). The clasts are predominantly local Mesozoic sandstone and siltstone up to 60 cm in diameter. Rounded Proterozoic clasts make up <1% of the

deposit. The conglomerate is matrix to clast supported. The matrix is coarse to fine, mostly quartz with lithics.

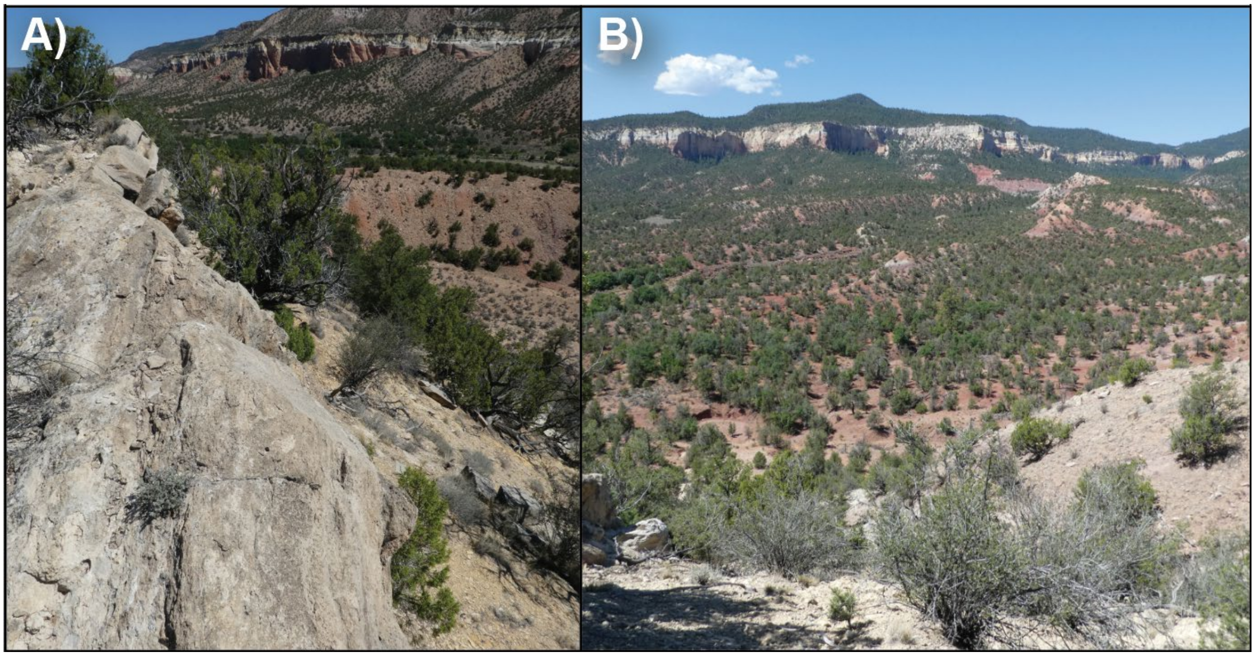


Figure 15. A) View from the top of the slump block looking north at the intact Todilto Formation limestone on Entrada Sandstone within the west-dipping slump block in the foreground. B) View of the current exposures of Entrada and Todilto 2 km to the west of this slump-block.

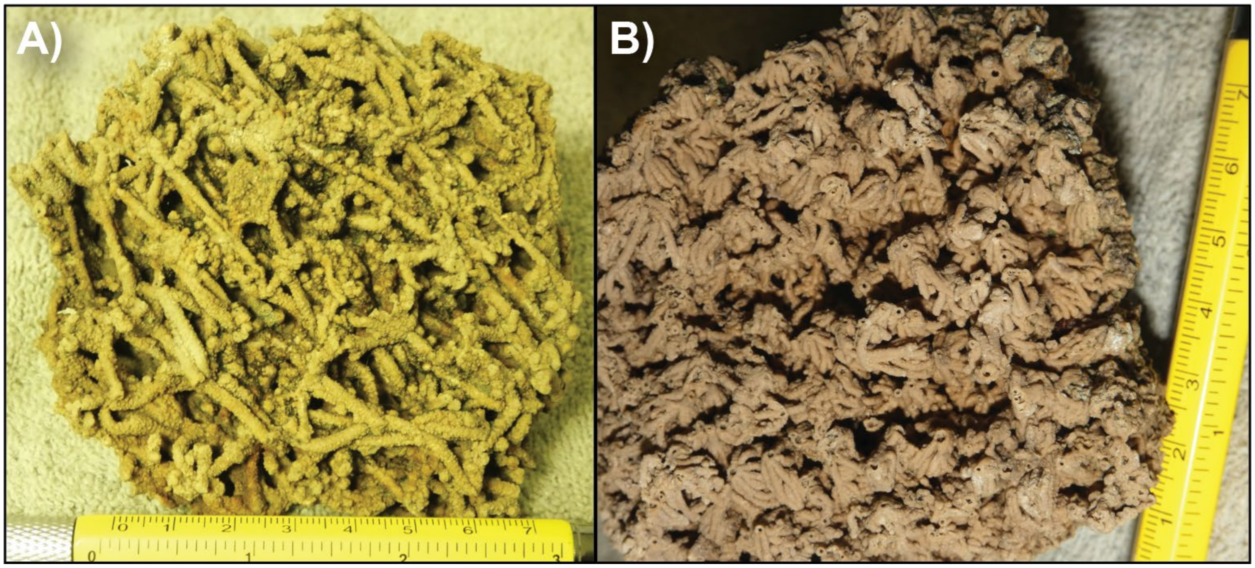


Figure 16. Photos of well-preserved plant fossils from a travertine deposit in Ojitos Canyon. A) twigs; B) possible flower(?) buds

GEOLOGIC STRUCTURES

Geologic structures are difficult to locate because of the thick forest cover on this quadrangle. Structures are now easier to see in areas affect by the forest fires on the Laguna Peak quadrangle in 2024 and 2025.

The very eastern edge of the French Mesa anticline lies along the western border of the quadrangle (Fig. 17). The top of the Chinle Group, the Entrada Sandstone, the Todilto Formation, and poorly exposed Morrison Formation capped by the Cretaceous Burro Canyon Formation, form a prominent west-facing escarpment on the east limb of the anticline, along the west edge of the map. The sedimentary rocks dip 15–30° to the east-northeast. The dips flatten eastward over a distance of 0.5–0.8 km.

Three northeast-striking folds deform the Burro Canyon and Morrison Formations just south of Mesa los Indios in Ojitos Canyon. The Burro Canyon Formation, Morrison Formation, and the Entrada Sandstone are folded across monoclines and a 0.8-km-wide asymmetric syncline. Within the folds, rocks are commonly fractured, and in some places minor faults offset the stratigraphy by one to two meters. Another structure is a southeast-down, northeast-striking fault that offsets thick sandstones in the upper part of the Brushy Basin and Westwater Canyon Members of the Morrison Formation. The offset along the fault is approximately 10 m. A parallel northeast-striking fault extends northeastward onto the Navajo Peak quadrangle near the monastery just north of the confluence of the Rio Gallina and the Rio Chama.

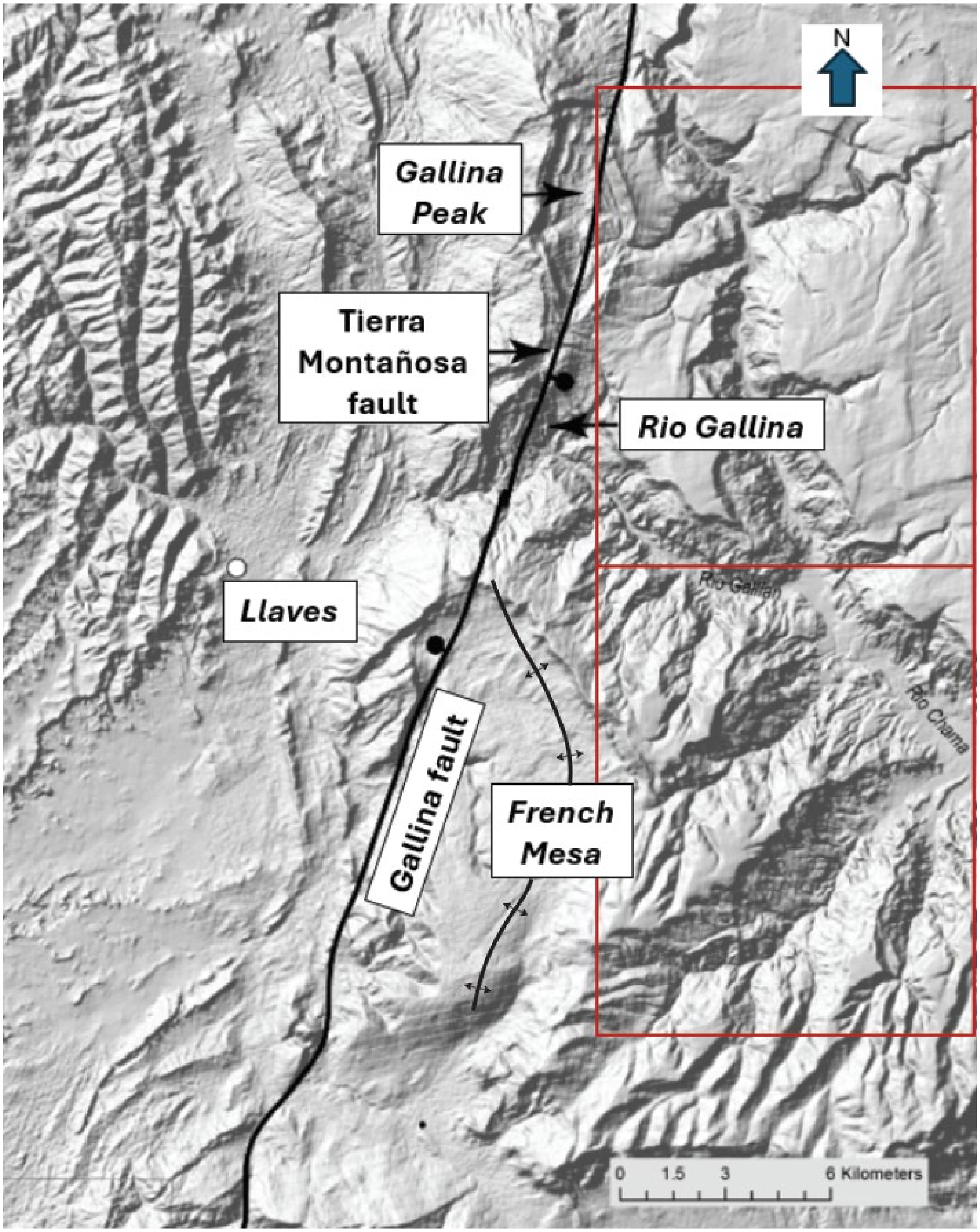


Figure 17. Hillshade map showing the larger structural context of the map area. The eastern limb of the French Mesa anticline makes up the western border of the Laguna Peak quadrangle (bottom red rectangle). Based on Woodward (1974).

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LAGUNA PEAK DMU

CENOZOIC

QUATERNARY

Spring Deposit

Qtr **Travertine (Holocene?)–**

White to tan calcium carbonate deposited by a paleospring (?) on a landslide composed of Mesozoic sandstone blocks on the north side of Ojitos Canyon. The travertine encases plant fossils, including twigs, sticks, and possible flower buds. Thickness varies from 0.3–1 m.

Alluvial Deposits

Qar **Recent alluvium (0 to 150 years old)–**

Unconsolidated clays, silts, sands, gravels, and cobbles including active channel and floodplain deposits. Also includes lowest terraces, which are found 1–5 meters above modern channel grade. Approximately 1–2 m thick.

Qay **Younger alluvium (late to middle Holocene)–**

Unconsolidated clays, silts, sands, gravels, and cobbles deposited by the Rio Gallina. Deposit forms an inactive alluvial terrace with a tread 3–6 m above modern channel grade. Approximately 1–6 m thick.

Qai **Intermediate alluvium (middle Holocene to late Pleistocene)–**

Unconsolidated clays, silts, sands, gravels, and cobbles deposited by the Rio Gallina. Deposit forms an inactive alluvial terrace surface with a tread 6–9 m above modern channel grade. Approximately 1–9 m thick.

Qao **Older alluvium (late Pleistocene)–**

Unconsolidated clays, silts, sands, gravels, and cobbles deposited by the Rio Gallina. Deposit forms an inactive alluvial terrace surface with a tread greater than 15 m above modern channel grade. Unit is less than 15 m thick.

Fan Deposits

Qfy **Younger fan deposits (Holocene)–**

Short:

Unconsolidated clays, silts, sands, pebbles, cobbles, and boulders deposited by debris flow events and sheetwash. Gravels are subangular to subrounded and include locally derived, Mesozoic sandstone clasts and Todilto Formation gypsum and limestone clasts. Occasionally incised by active channels. Unit is 1–10 m thick.

Long:

Unconsolidated clays, silts, sands, pebbles, cobbles, and boulders deposited by debris flow events and sheetwash. Commonly reddish in color, but brown and tan deposits are also present. Unit forms fan shapes at the bases of steep channels. Gravels are subangular to subrounded and include locally derived, Mesozoic sandstone clasts and Todilto Formation gypsum and limestone clasts. Deposits grade into and interfinger with adjacent Quaternary deposits. Occasionally incised by active channels. Unit is 1–10 m thick.

Qfi **Intermediate fan deposits (Holocene to late Pleistocene)–**

Short:

Unconsolidated clays, silts, sands, pebbles, cobbles, and boulders deposited by debris flow events and sheetwash. Contains moderately cemented to well-cemented intermediate-age fan deposits and unconsolidated gravels deposited by younger fans. Gravels are subangular to subrounded and include locally derived, Mesozoic sandstone clasts and Todilto Formation gypsum and limestone clasts. Unit is 1–10 m thick.

Long:

Unconsolidated clays, silts, sands, pebbles, cobbles, and boulders deposited by debris flow events and sheetwash. Commonly reddish in color. Unit forms fan shapes at the bases of steep channels. This unit contains moderately cemented to well-cemented intermediate-age fan deposits, as well as unconsolidated gravels deposited by younger fans. Gravels are subangular to subrounded and include locally derived Mesozoic sandstone clasts and Todilto Formation gypsum and limestone clasts. Deposits grade into and interfinger with adjacent Quaternary deposits. Occasionally incised by active channels. Unit is 1–10 m thick.

Qfo **Older fan deposits (late Pleistocene)–**

Unconsolidated clays, silts, sands, pebbles, cobbles, and boulders deposited by debris flow events and sheetwash. Commonly reddish in color. Gravels are subangular to subrounded and include locally derived, Mesozoic sandstone and Todilto Formation gypsum and limestone clasts. Unit forms gently sloping surfaces up to ~90 m above river grade. Unit is 1–10 m thick.

Terrace Deposits

QNg **Lag gravels (late Pleistocene to late Miocene?)–**

Unconsolidated lag deposit of pebble- to cobble-gravel preserved on a surface above the Entrada Sandstone on the south side of the Rio Gallina. Clasts include rounded Proterozoic quartzite, metaconglomerate, and granite and rounded yellow Mesozoic sandstone. The clasts are 1–5 cm in diameter. The locality is about 280 m above the modern elevation of the Rio Gallina.

Qtch1 **Rio Chama terrace 1 (late Holocene)–**

Short:

An allostratigraphic fluvial deposit below **Qtch2**. Consists of unconsolidated sand, pebbles, cobbles, and minor boulders. Clast-supported, with subrounded to well-rounded clasts; lithologies include quartzite, volcanics, and subordinate Mesozoic sandstone. Fine- to very coarse-grained sand. Tread height is 5–12 m above the river. Unit is 1–9 m thick. Age of 939–1,017 years before present (Chestnutt et al., 2019).

Long:

An allostratigraphic fluvial deposit below **Qtch2**. The unit consists of unconsolidated sand, pebbles, cobbles, and minor boulders. The unit is clast-supported, with subrounded to well-rounded clasts. Gravel lithologies include quartzite, volcanics, and subordinate Mesozoic sandstone (Chestnutt et al., 2019). Sand is fine- to very coarse-grained. The unit contains minor tabular beds of reddish gravelly sand. Tread height is 5–12 m above modern river grade. The unit is 1–9 m thick. The unit yielded a calibrated ^{14}C age of 939–1,017 years before present (Chestnutt et al., 2019).

Qtch2 **Rio Chama terrace 2 (late Pleistocene)–**

Short:

An allostratigraphic fluvial deposit above **Qtch1** and below **Qtch3**. Consists of unconsolidated sand, pebbles, cobbles, and minor boulders. Clast-supported, with subrounded to well-rounded clasts; lithologies include quartzite, volcanics, and subordinate Mesozoic sandstone. Fine- to very coarse-grained sand. Tread height is 6–38 m above the river. Unit is 1–9 m thick. Age of 34.0–35.5 kyr before present (Chestnutt et al., 2019).

Long:

An allostratigraphic fluvial deposit above **Qtch1** and below **Qtch3**. The unit consists of unconsolidated sand, pebbles, cobbles, and minor boulders. The unit is clast-supported, with subrounded to well-rounded clasts. Gravel lithologies include quartzite, volcanics, and subordinate Mesozoic sandstone (Chestnutt et al., 2019). Sand is fine- to very coarse-grained. The unit contains minor tabular beds of reddish gravelly sand. Tread height is 6–38 m above modern river grade. The unit is 1–9 m thick. The unit yielded a calibrated ^{14}C age of 34,003–35,513 years before present (Chestnutt et al., 2019).

Qtch3 **Rio Chama terrace 3 (late Pleistocene)–**

Short:

An allostratigraphic fluvial deposit above **Qtch2**. Consists of unconsolidated sand, pebbles, cobbles, and minor boulders. Clast-supported, with subrounded to well-rounded clasts; lithologies include quartzite, volcanics, and subordinate Mesozoic sandstone. Fine- to very coarse-grained sand. Tread height is 27–38 m above the river. Unit is 1–9 m thick. Age of 40.3–41.4 kyr before present (Chestnutt et al., 2019).

Long:

An allostratigraphic fluvial deposit above **Qtch2**. The unit consists of unconsolidated sand, pebbles, cobbles, and minor boulders. The unit is clast-supported, with subrounded to well-rounded clasts. Gravel lithologies include quartzite, volcanics, and subordinate Mesozoic sandstone (Chestnutt et al., 2019). Sand is fine- to very coarse-grained. The unit contains minor tabular beds of reddish gravelly sand. Tread height is 27–38 m above modern river grade. The unit is 1–9 m thick. The unit yielded a calibrated ^{14}C age of 40,339–41,408 years before present (Chestnutt et al., 2019).

Slope-wash, Alluvial, and Eolian Deposits

Qas **Alluvium and slope wash (Holocene)—**

Unconsolidated clay, silt, sand, and gravel deposited by alluvial channels and minor slope wash into valley bottoms. Sometimes includes eolian and colluvial deposits. Commonly adjacent to and interfingering with **Qsa**. Estimated thickness is 1–5 m.

Qsa **Slope wash and alluvium (Holocene)—**

Unconsolidated clay, silt, sand, and gravel deposited by slope wash and minor alluvial channels into small basins and hillslopes. Sometimes includes eolian and colluvial deposits. Forms smooth, sloped topography with nonexistent to shallowly incised channels. Estimated thickness is 1–5 m.

Mass-wasting Deposits

Qc Colluvium (Holocene to middle Pleistocene)–

Unconsolidated boulders, cobbles, pebbles, sand, silt, and clay forming thick, poorly sorted deposits from undivided mass wasting events, including topples, slides, earth and debris flows, and sheet-flow. Gravel lithologies include a variety of locally derived rocks. The unit is mapped where colluvial deposits obscure the underlying bedrock. Approximately 1–20 meters thick.

Qlsb Landslide slump blocks (Holocene to late Pleistocene)–

Short:

Generally coherent, down-dropped, and back-tilted linear blocks of Jurassic Entrada Sandstone and Todilto Formation that have been displaced from the canyon rim by shear failure, rotation, and lateral displacement of weak underlying rock (Chestnutt et al., 2019). Slump blocks are 220 m to more than 2.5 km from the modern canyon rim. Thickness of the deposits is 40-90 m.

Long:

Generally coherent, down-dropped, and back-tilted linear blocks of Jurassic Entrada Sandstone and Todilto Formation that have been displaced from the canyon rim by shear failure, rotation, and lateral displacement of weak underlying rock (Chestnutt et al., 2019). Slump blocks are 220 m to more than 2.5 km from the modern canyon rim. Slump blocks that are further from the canyon rim may have been "rafted" by later landslide events (Chestnutt et al., 2019). Thickness of the deposits is 40-90 m.

Qls Landslides, undivided (middle Holocene to late Pleistocene)–

Short:

Unconsolidated sand, silt, clay, pebbles, cobbles, and boulders deposited by rock falls, earth and debris flows, and rotational and translational landslides. Commonly displays landslide scarps, lateral margins, and toes. Contains jumbled, locally-derived rock types. Mapped where multiple landslides create larger complexes. Thickness is up to 60 m and highly variable.

Long:

Unconsolidated sand, silt, clay, pebbles, cobbles, and boulders deposited by rock falls, earth and debris flows, and rotational and translational landslides. Commonly displays landslide scarps, lateral margins, and toes. Contains jumbled, locally-derived rock types. The unit was mapped where landslide deposits lack obvious relative-age relationships, and where multiple landslides create larger complexes that are best mapped as a single unit. Thickness is up to 60 m and highly variable. Absence of a mapped landslide does not indicate the absence of a landslide hazard.

Qlsr **Recent landslides (late Holocene)–**

Short:

Unconsolidated sand, silt, clay, pebbles, cobbles, and boulders deposited by rock falls, earth and debris flows, and rotational and translational landslides. Contains jumbled, locally-derived rock types. Displays fresh landslide morphological features. Commonly crosscuts **Qlsi** and **Qlso**. Topography is moderately to very hummocky. Commonly unincised to minorly incised. Up to 60 m thick.

Long:

Unconsolidated sand, silt, clay, pebbles, cobbles, and boulders deposited by rock falls, earth and debris flows, and rotational and translational landslides. Deposits contain jumbled, locally-derived rock types. The unit displays fresh morphological features including flow banding, hummocks, lateral side-shear furrows and levees, and lobate toe deposits that over-thrust and spread over the preexisting ground surface (Chestnutt et al., 2019). **Qlsr** commonly crosscuts **Qlsi** and **Qlso**. Topography is moderately to very hummocky. Deposits are commonly unincised to minorly incised, with minor reworking by alluvial and colluvial processes. Thickness is up to 60 m and highly variable. Absence of a mapped landslide does not indicate the absence of a landslide hazard.

Qlsi **Intermediate age landslides (early Holocene to late Pleistocene)–**

Short:

Unconsolidated sand, silt, clay, pebbles, cobbles, and boulders deposited by rock falls, earth and debris flows, and rotational and translational landslides. Contain jumbled, locally-derived rock types. Displays muted landslide morphological features. Commonly crosscuts **Qlso** and is crosscut by **Qlsr**. Topography is moderately hummocky and minorly incised. Up to 60 m thick.

Long:

Unconsolidated sand, silt, clay, pebbles, cobbles, and boulders deposited by rock falls, earth and debris flows, and rotational and translational landslides. Deposits contain jumbled, locally-derived rock types. The unit displays muted landslide morphological features, including scarps, lateral margins, and landslide toes. **Qlsi** commonly crosscuts **Qlso**, but is crosscut by **Qlsr**. Deposits are characterized by overall smoothing of ground morphology by weathering and erosion, and development of drainage networks into the deposit (Chestnutt et al., 2019). These older deposits may be susceptible to creep during periods of high precipitation (Chestnutt et al., 2019). Thickness is up to 60 m and highly variable. Absence of a mapped landslide does not indicate the absence of a landslide hazard.

Qlso **Older landslides (late Pleistocene)–**

Short:

Unconsolidated sand, silt, clay, pebbles, cobbles, and boulders deposited by rock falls, earth and debris flows, and rotational and translational landslides. Displays subtle landslide morphological features. Commonly crosscut by **Qlsr** and **Qlsi**. Topography is smooth and reworked by alluvial and colluvial processes. Commonly disconnected from landslide source area. Up to 60 m thick.

Long:

Unconsolidated sand, silt, clay, pebbles, cobbles, and boulders deposited by rock falls, earth and debris flows, and rotational and translational landslides. Deposits contain jumbled, locally-derived rock types, with angular boulders often commonly exposed on the surface of the deposit (Chestnutt et al., 2019). The unit displays subtle morphological features, with poorly-defined scarps and gradational lateral margins. **Qlso** is commonly crosscut by **Qlsr** and **Qlsi**. Topography is smooth to moderately hummocky and commonly reworked by alluvial and colluvial processes. The unit is commonly disconnected from the landslide source area. Thickness is up to 60 m and highly variable. Absence of a mapped landslide does not indicate the absence of a landslide hazard.

MESOZOIC SEDIMENTARY ROCKS

CRETACEOUS

Kd **Dakota Sandstone (and Mancos Shale), undivided (Late Cretaceous)–**

Short:

Tan, fine- to medium-grained, moderately to well-sorted, commonly bioturbated, quartz sandstone with thin- to medium-tabular bedding that is locally cross-bedded. The sandstone is interbedded with tongues of Mancos Shale. The grains are subrounded to subangular. Asymmetric ripple marks are common. The unit is up to 50 m thick.

Long:

(includes the Encinal Canyon Member, Oak Canyon Member, Cubero Tongue, and Paguate Tongue of the Dakota Sandstone, and the Clay Mesa Tongue of the Mancos Shale; Owen et al., 2005). The oldest unit, the Encinal Canyon Member, is a tan fine- to medium-grained, moderately to well-sorted quartz sandstone with thin to medium tabular bedding that is locally cross-bedded. The grains are subround to subangular. Asymmetric ripple marks are common. This sandstone contains fossil wood and carbonaceous plant impressions are common near the base. The Cubero Tongue is fine- to medium-grained and well sorted. This sandstone has thin- to medium-tabular bedding and is usually bioturbated. The Paguate Tongue is fine- to medium-grained and well sorted. This sandstone has thin- to medium-tabular bedding, common bioturbation, and occasional symmetrical ripple marks. Abundant 0.5–1 mm brown-orange iron oxidation spots. Occasional herringbone cross-bedding and $CaCO_3$ cement. Intervening beds within the unit are variably carbonaceous and form either finely laminated gray sandstone or black shale intervals. Total unit thickness is up to 50 m in the map area.

Kbc **Burro Canyon Formation (Early Cretaceous)–**

Short:

White, light-yellow, orange, and buff, conglomeratic sandstone with lenses of green mudstone. Sandstone is fine- to medium-grained, quartzose, and kaolinitic. Small-scale trough cross-bedding associated with conglomeratic channels. Conglomerate clasts (<2.5 cm long) are mostly chalky, white chert and varicolored quartzite. Unit is 30–40 m thick.

Long:

White, light-yellow, orange, and buff, conglomeratic sandstone with thin lenses of green or, more rarely, red mudstone (Saucier, 1974). The sandstone is fine- to medium-grained, quartzose, and kaolinitic. Small-scale trough cross-bedding is associated with the conglomeratic channels. Conglomerate clasts are mostly chalky, white chert and varicolored quartzite. Clasts are up to 2.5 cm in diameter and subangular to subrounded. The base of the unit is typically more conglomeratic, while the top of the unit is more sandy. In Ojitos Canyon, lower beds within this unit contain angular clasts up to 20–30 cm in diameter of greenish-white well-sorted fine- to medium-grained sandstone likely derived from scouring of the underlying Brushy Basin Member of the Morrison Formation. Laminar low-angle wedge and high-angle planar wedge cross-bedding is common in the sandier portions of the formation. Some sandstone beds are massive. Occasional asymmetrical ripples, pitted texture, wood casts, and 0.5 cm iron cemented sandstone concretions are present. Slope forming mudstone horizons are 0.5–3 m thick, gray-green, black, or brown-orange, and $CaCO_3$ cemented. Basal contact is disconformable and locally displays significant paleotopography. The unit is 30–40 m thick.

JURASSIC

Morrison Formation

Jmb **Brushy Basin Member (Late Jurassic)–**

Short:

Variegated light-greenish-gray, light-gray, grayish-yellow-green, light-olive-gray, yellowish-brown, and drab-reddish-brown mudstones with discontinuous beds of cross-bedded to massive white, yellow, tan or grayish-tan sandstone. Up to 68 m thick.

Long:

The Brushy Basin Member is the youngest member of the Morrison Formation and consists of variegated light-greenish-gray, light-gray, grayish-yellow-green, light-olive-gray, yellowish-brown, and drab-reddish-brown mudstones with discontinuous beds of cross-bedded to massive white, yellow, tan or grayish-tan sandstone. Mudstones have moderate silt and minor, very fine sand content. Sandstone interbeds are poorly to moderately sorted, fine- to coarse-grained, and subangular to well-rounded. The iron-bearing minerals in these sandstones are commonly altered to 2–4 mm oxidation spots, giving the sandstones a speckled appearance on weathered surfaces. Sandstones are typically moderately to well-indurated, and occasionally contain green rip-up clasts, burrows, and large (2–4 m), spherical, iron-cemented concretions. The basal contact is conformable, but abrupt, with the underlying Westwater Canyon Member of the Morrison Formation. On the north side of Ojitos Canyon, the upper part of the Brushy Basin Member of the Morrison Formation contains stacked cross-bedded sandstone beds that form continuous cliffs that are 6–10 m high. Upper contact with the overlying Burro Canyon Formation is sharp and disconformable with significant paleotopography. The unit is up to 68 m thick.

Jmw **Westwater Canyon Member (Late Jurassic)–**

Short:

White to buff, ledge-forming, laminated to trough cross-bedded sandstone with occasional conglomeratic sandstone, and abundant horizons of mudstone rip-up clasts. Poorly sorted, fine- to coarse-grained, subangular to well-rounded. Feldspar is commonly altered to clay. Common 0.5–1.0 cm light-green to yellowish oxidation spots. This unit is discontinuous. Up to 50 m thick.

Long:

The Westwater Canyon Member is the middle member of the Morrison Formation. This unit consists of white to buff, ledge-forming, laminated to trough cross-bedded sandstone with occasional conglomeratic sandstone, and characteristic horizons of mudstone rip-up clasts. Channel forms are common. The sandstone is fine- to coarse-grained and poorly sorted; sand grains are subangular to well-rounded. Feldspar is usually altered to clay, forming either white clay clots, or weathered out to form a pitted texture. Common 0.5–1.0 cm light-green to yellowish oxidation spots. Intervals of red and green silty mudstone rip-up horizons reach 6–8 m above base while isolated rip-ups are found throughout; commonly scoured by sandstone channels. Variable thickness throughout the quadrangle, thin or locally absent except in middle Cañada de la Presa, middle Ojitos Canyon, and upper Cañada de los Fuertes, where it is present. Upper contact abrupt but conformable with overlying Brushy Basin Member of the Morrison Formation. Unit thickness ranges from 0–50 m.

Jmr Recapture Member (Late Jurassic)–

Short:

Maroon to white sandstone, siltstone, and sandy siltstone. Sandstones are very fine- to medium-grained, poorly to moderately indurated and occasionally contain limestone nodules and mud rip-up clasts. Siltstones are red, green, and white with variable clay and sand content. Thickness is 75–125 m.

Long:

The Recapture Member is the basal member of the Morrison Formation. This unit consists of drab maroon to grayish-red or white to gray sandstone, siltstone, and sandy siltstone. Sandstones are light-maroon to whitish, very fine- to medium-grained, poorly to moderately indurated, and are occasionally $CaCO_3$ cemented. Sandstones are found in 5–10 cm thick beds with 0.25–1 cm laminae, and commonly display platy or flaggy bedding. Occasional intervals containing limestone nodules and/or mud rip-up clasts are present throughout the unit. Siltstones are red, green, and white with variable clay and sand content. Siltstones are occasionally scoured by sandstones. The unit is 75–125 m thick.

San Rafael Group

Jtg Todilto Formation, where gypsum is present (Middle Jurassic)–

Short:

Consists of the lower Luciano Mesa Member (2–5 m thick), which is mostly a thinly laminated (0.25–1 cm), dark-gray or yellowish-gray, kerogenic limestone and calcareous shale. The overlying Tonque Arroyo Member (45–60 m thick) is white to light-gray, finely crystalline to megacrystalline gypsum interbedded with carbonate. Total Todilto Formation thickness is up to 65 m.

Long:

The Todilto Formation consists of a lower, limestone-dominated interval (Luciano Mesa Member), which is locally overlain by a gypsum interval (Tonque Arroyo Member; Lucas et al., 1985, 1995; Kirkland et al., 1995). The Luciano Mesa Member is 2–5 m thick and consists mostly of thinly laminated (0.25–1 cm), dark-gray or yellowish-gray, kerogenic limestone, and calcareous shale. The overlying Tonque

Arroyo Member is up to 60 m of white to light-gray, finely crystalline to megacrystalline gypsum interbedded with carbonate. A limestone microbreccia left by dissolution of the gypsum of the Tonque Arroyo Member is present at several places above the Luciano Mesa Member. Where the Tonque Arroyo Member is missing, the Luciana Mesa Member is too thin to map and is grouped into unit **Jet**. Total Todilto Formation thickness is up to 65 m, where the Tonque Arroyo Member is present.

Je Entrada Sandstone (Middle Jurassic)–

Short:

White, yellow, grayish-orange and red, cross-bedded, cliff-forming sandstone. Very fine- to medium-grained, moderately well-sorted sandstone. Cross-beds are meters-wide and formed from eolian dune-forming processes. Top of the unit is conformable with the Luciano Mesa Member of the Todilto Formation, and the base is unconformable with the Rock Point Formation of the Chinle Group. The unit is 55–75 m thick.

Long:

The Entrada Sandstone is a white, yellow, grayish-orange and red, cross-bedded, ripple-laminated, cliff-forming sandstone. The Entrada Sandstone is a very fine- to medium-grained, moderately well-sorted sandstone that forms bold cliffs along escarpments and mesa tops. Cross-beds are meters-high or “meter-scale” and formed from eolian dune-forming processes. Top of unit is conformable with the Luciano Mesa Member of the Todilto Formation, and the base of the Entrada Sandstone is unconformable with the Rock Point Formation of the Chinle Group. The unit is 55–75 m thick (Fitter, 1958; Crouse et al., 1992).

Jet Todilto Formation and Entrada Sandstone (Middle Jurassic)–

A combined unit containing both the Entrada Sandstone and lower, limestone-dominated Luciano Mesa Member of the Todilto Formation, which caps the Entrada Sandstone. Luciano Mesa Member consists of gray, laminated, kerogenic limestone and calcareous shale. Entrada Sandstone consists of yellow, grayish-orange, and red, cross-bedded and ripple-laminated, cliff-forming eolian sandstone. The unit is 55–75 m thick.

TRIASSIC

Ŧcu Upper Chinle Group (Late Triassic)–

Short:

The upper Chinle Group includes mudstones, siltstones, and sandstones of the Rock Point and Petrified Forest Formations. The Rock Point Formation consists of reddish-brown beds of siltstone and fine-grained sandstone. The underlying Painted Desert Member of Petrified Forest Formation is predominantly red mudstone with minor sandstone. The thickness of this combined unit is 180–190 m.

Long:

An informal upper unit that includes mudstones, siltstones, and sandstones of the Rock Point and Petrified Forest Formations. The Rock Point Formation consists of 5–10 m of reddish-brown, and grayish-red beds of siltstone and fine-grained sandstone. The top of the Rock Point Formation is marked by a sharp, unconformable contact with the Entrada Sandstone (the J-2 unconformity of Lucas, 1993), whereas the bottom of the unit is conformable with the underlying Petrified Forest Formation. The Petrified Forest Formation is approximately 170 m thick and contains two members, the Painted Desert Member and the Mesa Montosa Member. The overlying Painted Desert Member is a reddish-brown, bentonitic mudstone with thin ledges and lenses of ripple-laminated or cross-bedded sandstone; petrified wood is common. The base of the Painted Desert Member is a thick mudstone bed above the highest sandstone ledge of the Mesa Montosa Member. The underlying Mesa Montosa Member is primarily sandstone, with lesser amounts of mudstone and siltstone that range in color from reddish-brown to green; sandstone beds are very fine- to fine-grained, lightly $CaCO_3$ cemented, micaceous, and ripple-laminated to thinly-laminated; ripples are asymmetric. The Mesa Montosa Member is conformable with the underlying Poleo Formation.

TRcl **Lower Chinle Group (Late Triassic)–**

Short:

Sandstone and conglomerate; commonly cemented with $CaCO_3$. Sandstones are yellow-brown and yellow-gray, fine- to medium-grained; angular to subangular; contain mica, feldspar, and lithic grains. Conglomeratic intervals contain siltstone, nodular calcrete, chert, and quartzite clasts. Only the top few meters are exposed on the Laguna Peak quadrangle.

Long:

The lower Chinle Group primarily consists of the Poleo Formation. This unit is dominantly sandstone with subordinate conglomeratic sandstone, conglomerate, silty-sandstone, and mudstone. Sandstones are yellow-brown and yellow-gray, quartzose, fine- to medium-grained, angular to subangular, characteristically micaceous, and cross-bedded. Sandstones contain occasional rip-up clasts, potassium feldspar, mica, and rare plant impressions. The matrix includes abundant potassium feldspar and exotic lithics including fine-grained sedimentary, low-grade metamorphic, and felsic igneous clasts; commonly $CaCO_3$ cemented. Conglomerate is interbedded with horizons of very coarse sandstone. Silty sandstones are gray to blue with abundant silt and minor very fine sands; thinly laminated and micaceous. This unit is exposed along the banks of the Rio Chama below the confluence of the Rio Chama and the Rio Gallina. The upper contact is gradational into the overlying Mesa Montosa Member of the Petrified Forest Formation. Only the top few meters are exposed on the Laguna Peak quadrangle.

CROSS SECTION ONLY

Pc **Cutler Formation (Early Permian)—**

Red, maroon, and white granitic siltstones, sandstones, and conglomerates.

₽m **Madera Formation (Pennsylvanian)—**

Arkosic sandstone and limestone.

pꞒu **Proterozoic rocks (Proterozoic)—**

Igneous and metamorphic rocks ranging from 1.7 to 1.4 Ga.